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Potential contribution of geothermal energy to climate change adaptation: A case study of the arid and semi-arid eastern Baringo lowlands, Kenya☆

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ABSTRACT

The impacts of recurrent droughts have increased vulnerability and reduced the adaptive capacity of the people living in arid and semi-arid lands (ASALS) of Kenya. Current interventions are short-term and curative in nature, hence unsustainable. Some of the most arid and semi-arid lands are located within the Kenyan Rift system, which has an estimated geothermal potential of about 7000 to 10,000 MWe, out of which only 200 MWe has been developed, and about 5000 MWe planned by 2030. Recent power sector reforms have built institutional structures that will accelerate development of geothermal energy. The paper analyses the potential use of geothermal energy resources in eastern Baringo lowlands between Lake Bogoria and Silali prospects, which has an estimated potential of >2700 MWe, in creating the necessary adjustments needed to adapt to the impacts of recurrent droughts by locals. Opportunities for direct and indirect uses of geothermal energy exist in climate vulnerable sectors, such as, agriculture, fisheries, water, livestock production as well as alternative income generating activities such as, tourism, micro enterprises, aloe, honey and beeswax production, fabric dyeing and others using resources sourced from within a 50 km radius. The possibility of accelerated geothermal development and proposed utilisation schemes in causing maladaptation if unsustainably implemented is also discussed. The paper draws a Lindal diagram adapted to the study area showing potential utilisation in the above sectors, and new flow diagram showing potential for cascaded use of geothermal hot water through the different processes. An estimated capacity of 100 MWt and 100 MWe can be used in the potential utilisation schemes discussed in this article to meet local adaptation and lighting needs and much less in a cascaded process. Potential barriers and possible solutions are also discussed. The study concludes that geothermal energy is a vital option for adaptation in the study area if sustainably used.

Contents

Abbreviations: ASALS, arid and semi arid lands; CITIES, Convention on International Trade in Endangered Species; CDF, Community Development Fund; EIA, environmental impact assessment; ERC, Energy Regulatory Commission; FiT, feed in tariff; GFD, general food distribution; KARI, Kenya Agricultural Research Institute; KEFRI, Kenya Forestry Research Institute; KES, Kenya Shilling; KWS, Kenya Wildlife Service; kWht, kilowatt hour thermal; kWhe, kilowatt hour electric; KVDA, Kerio Valley Development Authority; MT, metric tons; MWe, megawatt hour electric; MWt, megawatt hour thermal; NEMA, National Environment Management Authority; SEA, Strategic Environmental Assessment; USD, United States dollars; WFP, World Food Programme; WWF, World Wildlife Fund.

☆ The research was done in 2010. Information on geothermal prospects may improve based on new results from the planned exploration and production drilling in the next 3 to 5 years.

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1. Introduction

Recurrent droughts in Kenya, especially in the last decade, have increased vulnerability of people living in the arid and semi-arid areas (ASALS). Some of the current interventions taken during drought are short-term and curative in nature and cannot build long term sustainability and adaptive capacity of the affected. Moreover, the role of a conventional clean energy source like geothermal has been forgotten in addressing adaptation beyond sustaining the country's drought vulnerable hydropower plants.

The estimated geothermal resource potential within the Kenyan Rift Valley (Fig. 1) alone stands at about 7000 to 10,000 MWe out of which only 200 MWe[1] is currently being exploited with additional 280 MWe, scheduled for commissioning in 2014 [1]. The geothermal resources in the Rift Valley, most of which are undeveloped, coincide with the most drought prone areas of the country. Currently, the government focus is to accelerate geothermal development mainly for electricity production with the aim of developing >1600 MWe by 2016 and >5000 MWe by 2030 [1]. However, both electrical (indirect use) and non-electrical (direct use) geothermal resources should be developed not just to meet

[1] Subject to rapid change due to accelerated geothermal development.

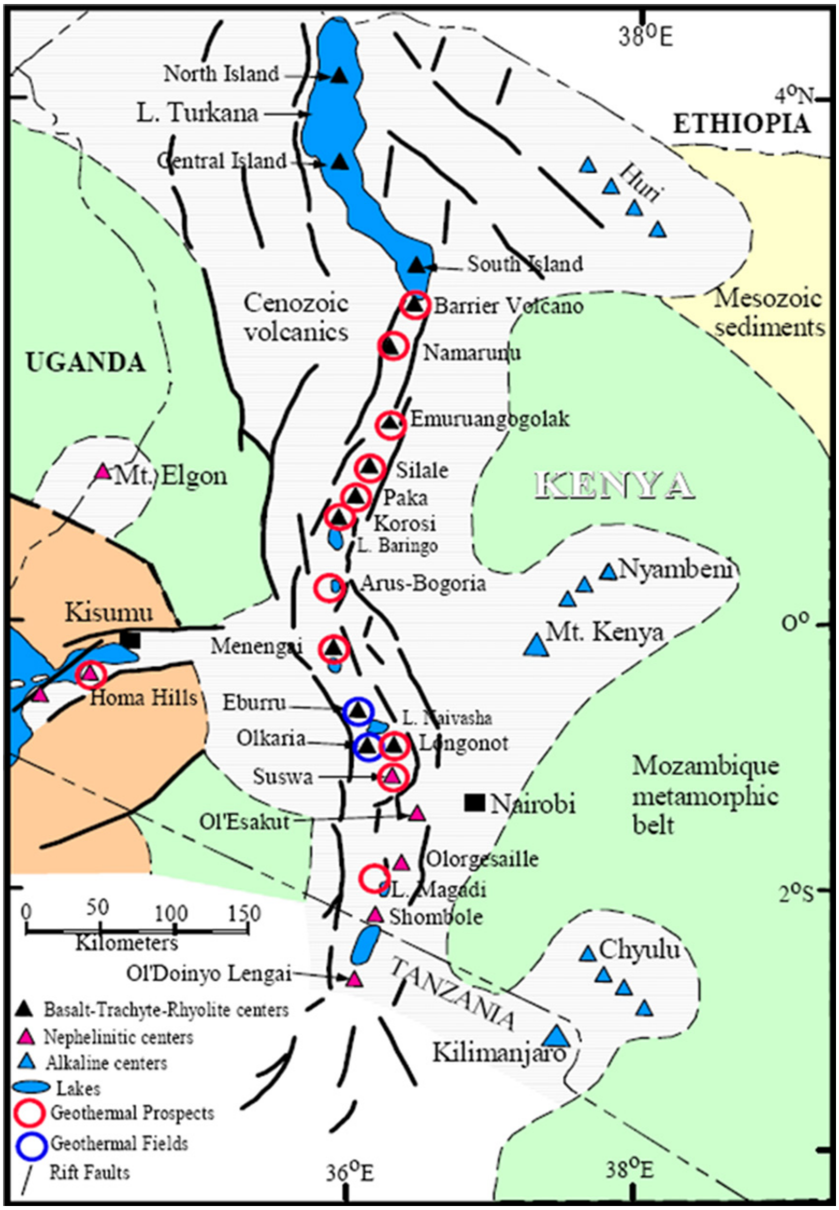

Fig. 1. Geothermal prospects along the Kenyan Rift Valley. The study area falls between Bogoria and Silali Volcano prospects.

electrical needs, but also to enhance the adaptive capacity of the drought prone communities where the resource occurs. Recovery of geothermal energy in non-electrical applications has a greater efficiency than recovery for electrical applications [2]. Geothermal energy uses existing technology and straight forward engineering that has been demonstrated throughout the world [3]. Combining direct and indirect uses especially in a cascade of activities can have a significant impact on climate vulnerable sectors such as agriculture, fisheries, water, livestock production, as well as alternative income generating activities such as tourism, micro and macro enterprises, aloe, honey and beeswax production to build local adaptive capacity re-current droughts.

Geothermal energy could meet 3% of global electricity demand (compared to 0.1% in 2008), and 5% global heat by 2050. The possible role and contribution of the projected geothermal energy deployment in mitigation of climate change have been scoped and documented for the Intergovernmental Panel on Climate Change (IPCC) by Goldstein et al. and others [4]. Peer reviewed literature on geothermal energy and adaptation is scarce. Opportunities for synergies between mitigation and adaptation in geothermal projects are discussed by Ogola et al. [5]. The impact of climate change on geothermal energy efficiency and the potential use as ground source heat pumps for climate proofing are also mentioned by Wilbanks et al. [6] and World Bank [7].

In this article, the potential for geothermal use in adaptation within the drought stricken eastern Baringo lowlands in the Marigat and East Pokot districts with an unexploited potential of about 2700 MWe [1] is analysed.

1.1. Objective of the study/research questions and methods

The objective of this study is to assess opportunities for low and high temperature utilisation of geothermal resources between the Bogoria and Silali prospects in alleviating the impact of recurrent droughts. The key research questions are: Can geothermal utilisation create the necessary adjustments needed to reduce the impact of recurrent drought? Can accelerated geothermal utilisation undermine local adaptation to climate change? What barriers

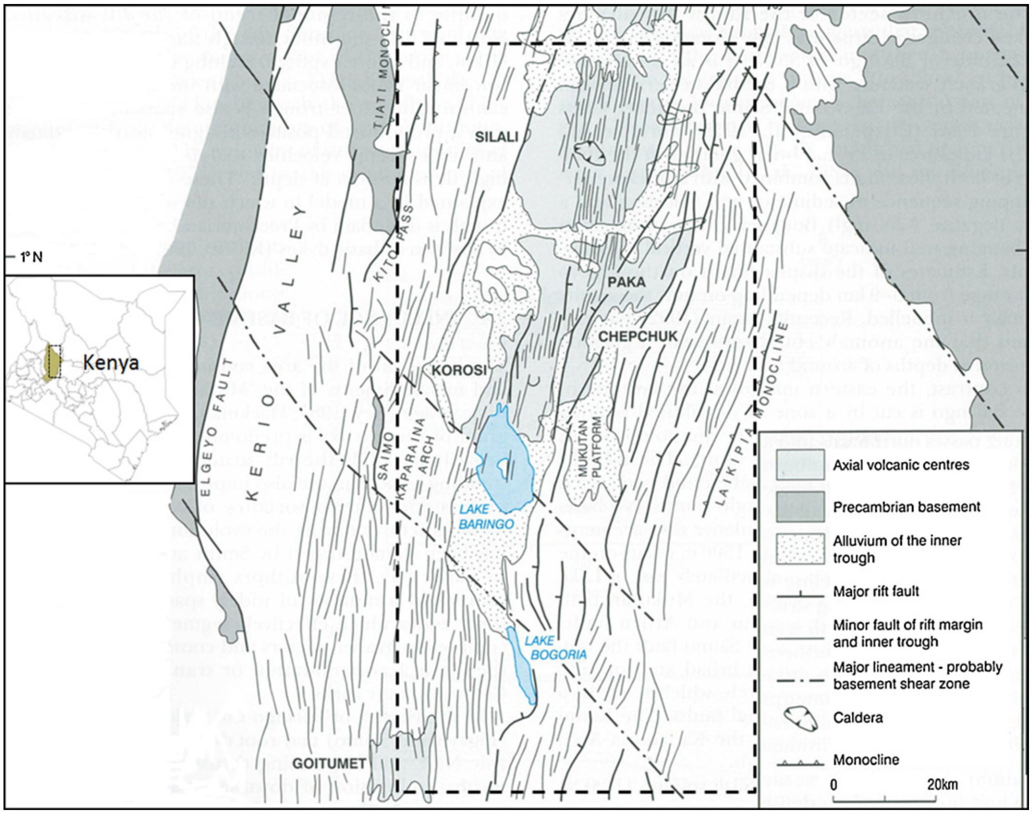

Fig. 2. Basic geology and structures of geothermal prospects in the study area.

Source: Dunkley et al. [9].

in the study area will undermine geothermal utilisation in adaptation to climate change?

The study employed field research, extensive interviews with local institutions and government officials, local community members and field observation. Literature review on geothermal utilisation from different countries and available technology and their relevance to the study area was also used.

Section 2 gives a brief discussion on the background of the study area, as well as the impact of drought and geothermal resources in the study area. Section 3 highlights the current non-commercial utilisation, while Section 4 focuses on the potential for geothermal utilisation, its link to adaptation, and potential for causing maladaptation, Section 5 gives a summary of the utilisation potential in a Lindal diagram and estimates the energy required for adaptation. Discussion and conclusion are presented in Sections 5 and 6 respectively.

2. Description of the study area

2.1. Location of the study area

The study area, which is partly located in north rift and central rift geothermal fields of the Kenyan Rift, is composed of two parallel sub-basins, i.e., Kerio Valley and the tectonically active Baringo–Bogoria sub-basin which are separated by the Tugen (Kamasia) block. The Kerio sub-basin is a typical half-graben, >8 km deep, while the Baringo Basin is 7 km deep filled by alternating fluvial and lacustrine sediments and thick piles of volcanics [8]. The study focused on the Baringo–Bogoria graben, commonly known as the eastern lowlands where geothermal activity is present (Fig. 2).

Administratively, the study area covers the new Marigat and East Pokot districts located in Baringo County, including areas south of Turkana (which covers part of Silali Volcano) and south of Lake Bogoria (the southern part of the lake is outside Marigat district boundary, but falls within the Lake Bogoria prospect).

2.2. Socioeconomic status and activities of the study area

The study area is characterised by recurrent droughts, inadequate infrastructure, land degradation, poor market access, insecurity, inadequate freshwater and firewood, poverty and high vulnerability to diseases and hunger.

The region ranks highly on the nationwide poverty index with 60% of the households living below the poverty line (USD 1.25/day) [10] and at least 62% of which are food poor [11]. Poverty levels are volatile and depend on extreme weather events and conflicts. In years of crisis, the levels in Marigat can rise to 67% and East Pokot to about 70–73% [12].

The main economic activities in the region are nomadic pastoralism, agropastoralism, bee keeping, fishing, local aloe production, irrigated and rain fed agriculture and tourism (Fig. 3).

Energy consumption in the study area is dominated by wood fuel which constitutes about 99% of energy used for cooking, lighting and other socioeconomic activities in the remote parts of the two districts, while kerosene and others constitute $\leq$0.5% [14]. About 90% of households in East Pokot use firewood for lighting [15] and at least <1% of the population had access to electricity at the time of the study. Despite the high potential in wind, solar and geothermal resources, their utilisation for modern energy services largely remains untapped due to low investment of energy infrastructure in the region [16].[2] To fast track geothermal development in the north rift, development of 800 MWe by 2017 between Lake

[2] Electrification is currently in progress in parts of the study area and expected to improve with completion of the first geothermal power plants in the region.

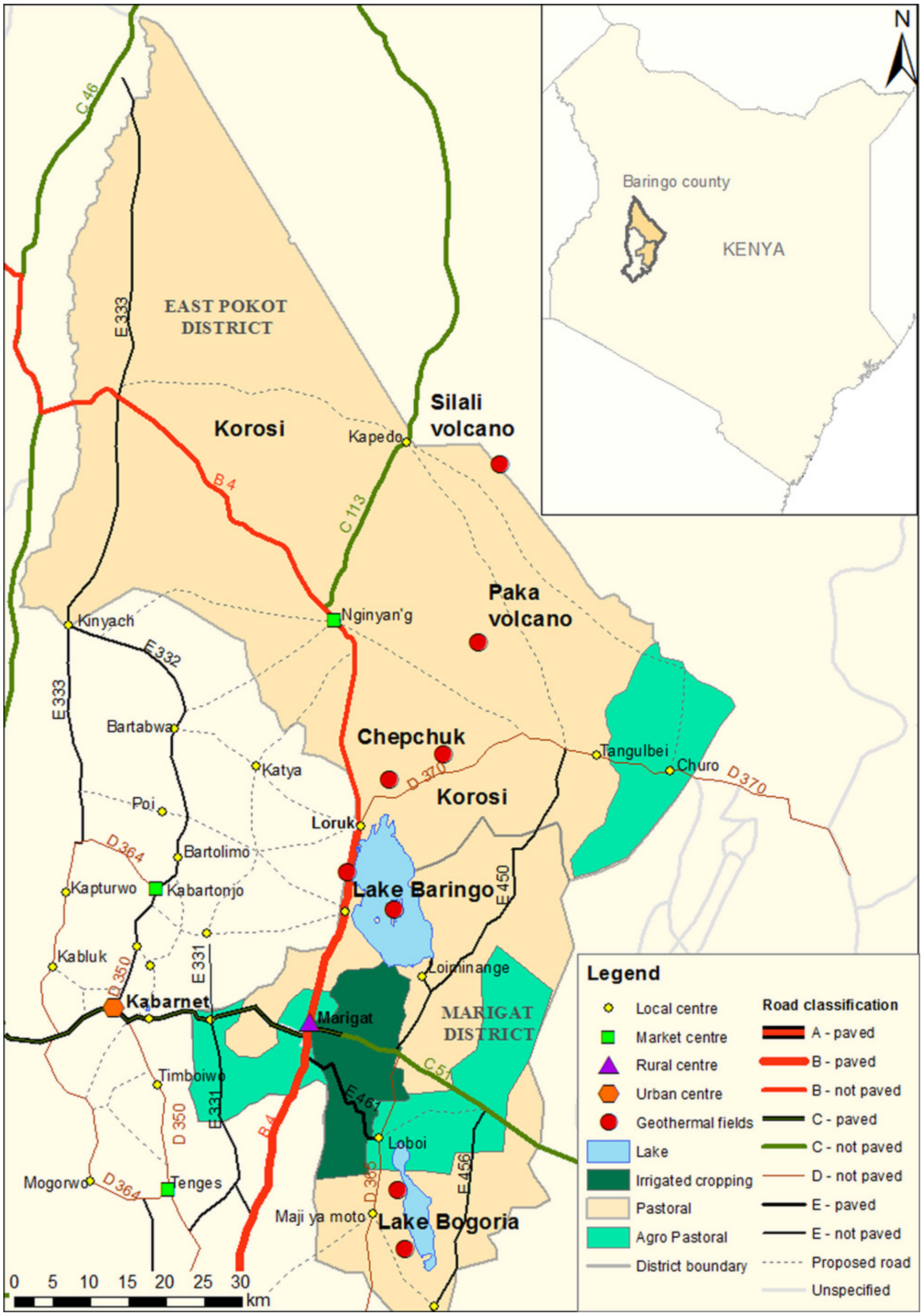

Fig. 3. Livelihood map and roads of East Pokot and Marigat Districts of Baringo County. Inhabitants of the study area engage in nomadic pastoralism, agro pastoralism and some irrigated farming in Marigat. The roads in East Pokot are not paved, and parts of the few light bitumen (paved) roads in Marigat District are run down by floods due to high soil erodibility.

Source: Authors of this Article.

Baringo and Silali is scheduled to start in 2012, with a target of eight geothermal power plants with an output of 100 MWe each from at least 200 geothermal wells in the first phase. A second phase of 400 MWe by 2019 and another 400 MWe by 2023 will follow [17].

2.3. Impact of drought

The low level of development, harsh climatic conditions and high dependency on climate sensitive natural resources in the study area have increased vulnerability of the resident communities to recurrent droughts creating a vicious cycle of poverty.

Rainfall is bimodal and about 50% reliable [11]. Variation in rainfall occurs on a range of time scales, including El Nino and La Nina periods, i.e., every 5–7 years [18]. The major recent droughts in Kenya and in the study area occurred in 1972–1973, 1982–1984, 1991–1992, 1999–2000, 2004–2006, 2008–2009, 2011 with El Nino in 1997–1998 and 2010.

Estimated household livestock deaths from these droughts vary between 50 and 90% [19,20]. Locals are forced to engage in extreme coping strategies like eating animal carcasses, borrowing food from relatives, taking food from shops on credit, eating wild fruits and honey, and constant migration for pasture and for casual labour. The

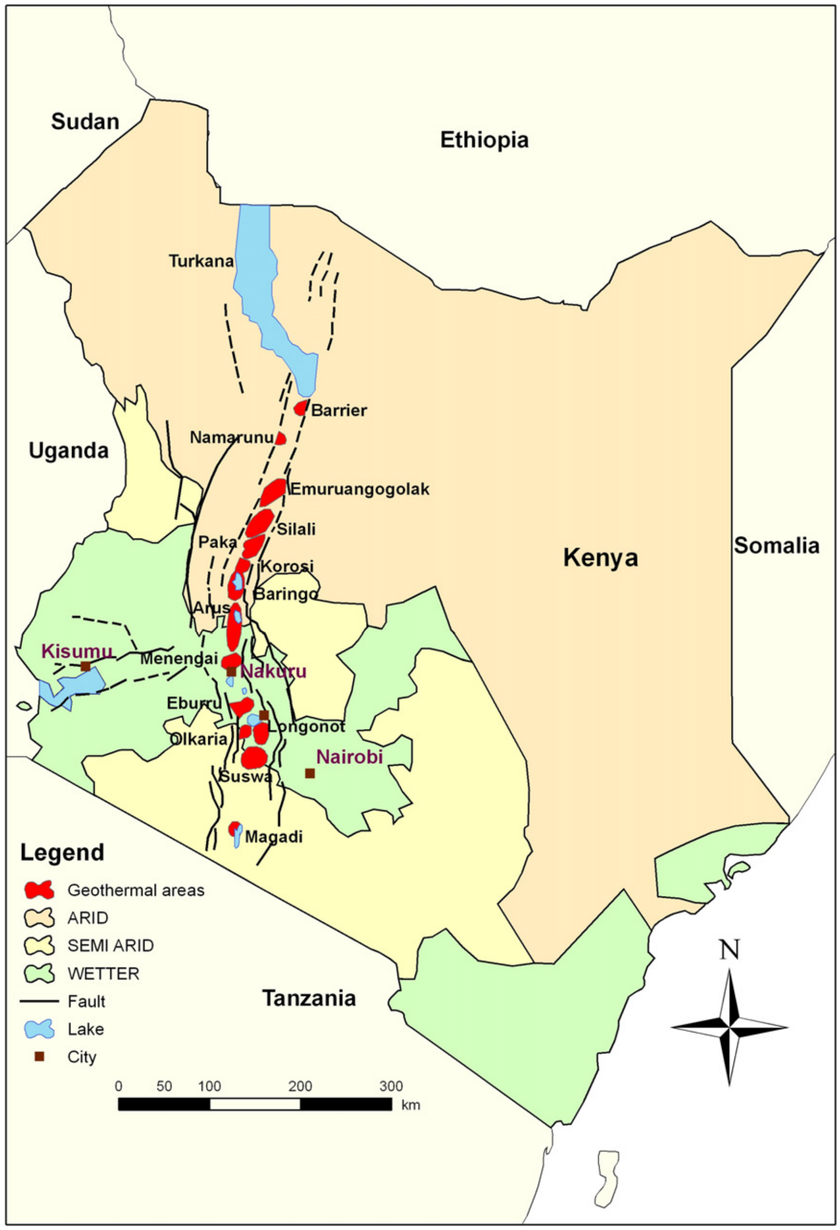

Fig. 4. Correlation between aridity and geothermal prospects in Kenya.

Source: Ogola [23].

locals are also shifting from cattle dominated livestock composition to goats and to some extent camels which are more resilient to drought.

Government intervention includes food distribution through food for asset (FFA) and general food distribution (GFD), as well as running school feeding programmes in collaboration with the World Food Programme (WFP) and the Ministry of Education [21]. In 2009, World Vision distributed approximately 1000 MT of food per month to the East Pokot and Marigat districts [22]. The approximate cost per MT of distributed food was: maize: USD 400/ton, corn meal: USD 400/ton, pulses: USD 500/ton, vegetable oil: USD 1000/ton, and corn soya blend: USD 500/ton. Other government mechanisms include slaughter destocking, tracking of water, construction and repair of boreholes.

Despite availability of geothermal energy resources (Fig. 4), there is still no meaningful investment in alternative economic activities that would help local communities to adapt to the adverse impacts of drought.

2.4. Geothermal prospects in the study area

2.4.1. Lake Bogoria prospect

Lake Bogoria has a surface area of approximately 35 km^2 and is about 10 m deep. Geothermal surface manifestations are presented by steam jets, hot springs, geysers, fumaroles, steaming grounds, mud pools, and hydrothermal rock alterations (Fig. 5). The lake is fed by nearly 200 hydrothermal springs along the shore, and four seasonal rivers, Waseges-Sandai, Loboi, Emsos and Mogun.

The springs occur in three main clusters, Loburu, Chemurkeu, and the Mwanasis-Kibwu-Losaramat areas. Hot springs at Loburu and Chemurkeu have a shallow aquifer with temperatures of about 100 °C, while the southern Mwanasis-Kibwu-Losaramat hot springs have a deeper lying aquifer with temperatures of about 170 °C [24,25]. Studies by KenGen indicate possible reservoir temperatures of <200 °C from gas geothermometry using hydrogen sulphide gas [26]. Hot springs at Lake Bogoria are rich in CO_2 and recharged mainly by meteoric water. At Arus, 15 km southwest of

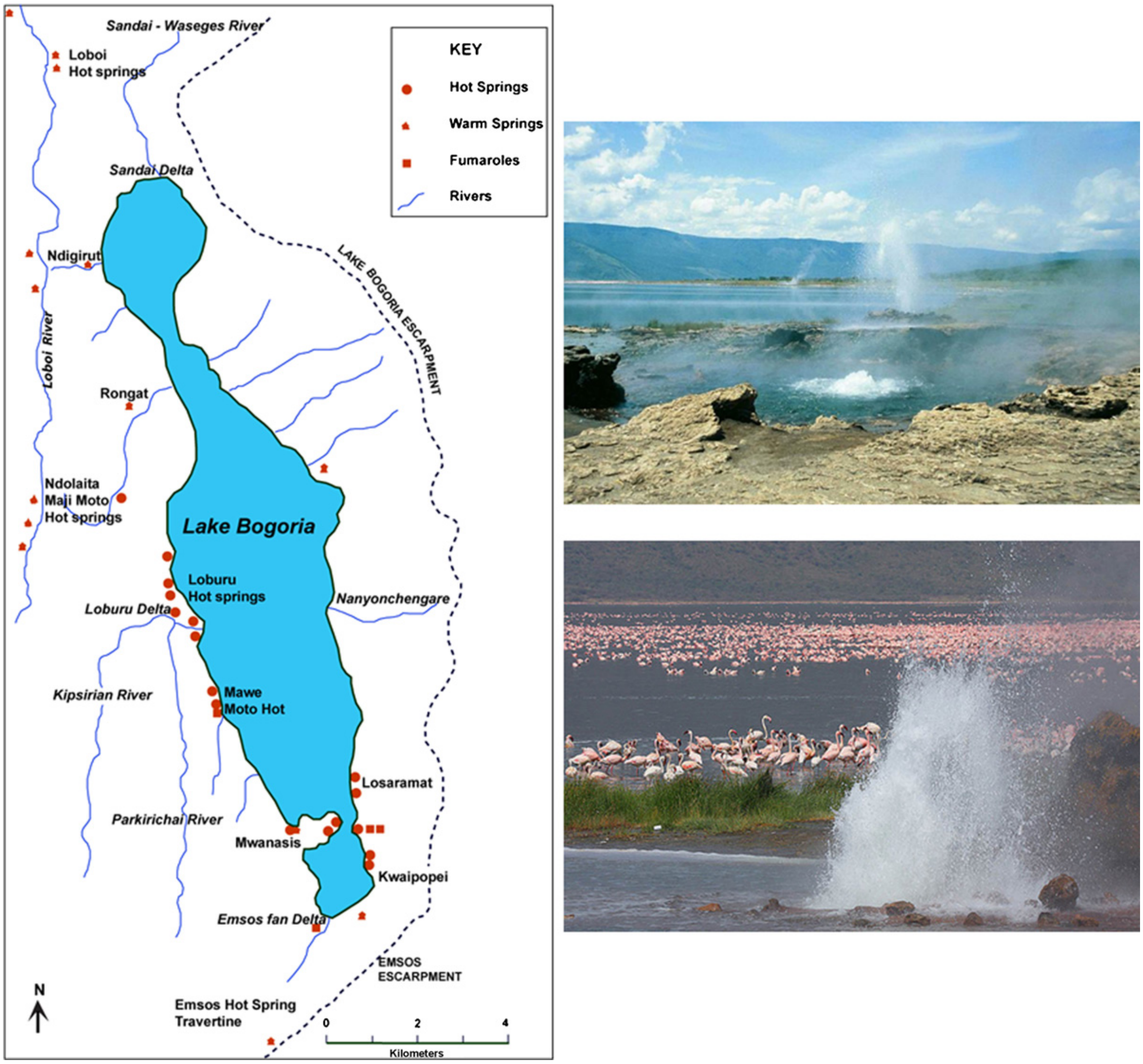

Fig. 5. Map and photos of the Lake Bogoria geothermal prospect showing surface thermal manifestations and the Lesser Flamingos.
Source: Modified from McCall [31].

Loburu, and at Esageri, which lies 35 km southwest of Lake Bogoria, fumaroles discharge CO_2 gas that is up to 99% pure [27–29]. The estimated potential for the Bogoria and Arus prospects are 200 MWe each [30]. Arus is mentioned in this article due to its close proximity to Lake Bogoria but is outside the boundary of this study.

2.4.2. *Lake Baringo prospect*

Geothermal activity is present along the NE peninsula of the Ol Kokwa Island of Lake Baringo commonly known as the Soro hydrothermal system [8,32]. Fumaroles and small ephemeral mud pots are present in slightly higher ground nearer the scarp with extensive hydrothermal alteration. The hot spring temperature ranges between 83 °C and 96.5 °C. Several studies indicate that the thermal springs of Ol Kokwa Island can be derived from two broad hydrochemistry categories. The first category consists of waters originating from deep reservoirs of regional groundwater with high chloride concentration, and a lake water component and with a temperature of ~170 °C [33,9,32]. The second group is of dilute spring waters found near sulphurous fumaroles and derived from condensation of fumarolic steam in the lake water–meteoric water mixing series [9]. Several geothermometers and in situ geothermal gradient give an estimated depth of the main thermal fluid reservoir of 300–900 m below the ground and an equilibrium temperature of 170–200 °C and a thermal gradient of about 200 $°C^{-1}$ [9,34,35].

The second prospect is located NW of the Lake Baringo and another potential site is where the “Baringo geyser”, erupted in early April 2004 during drilling of a community freshwater borehole at Chepkoiyo village, 6.5 km west of Lake Baringo is shown in Fig. 6. The Chepkoiyo incident confirms that hot water is present at shallow depths [34]. Fluid geothermometry indicates reservoir temperatures of >200 °C near the Chepkoiyo well [35] (Fig. 6). The heat source is due to dyke swamps along fault lines. The current potential for geothermal energy of the prospect is estimated at 200 MWe [30].

2.4.3. *Korosi/Chepchuk prospect*

The Korosi shield volcano lies at the northern end of Lake Baringo and does not contain a summit caldera. Fumaroles and hot steaming ground occur around the summit cones and NW flanks and extend over an area of 30 km^2 [36].

Geothermal manifestations occur along N–S and NNE–SSW trending faults and to a lesser extent in the craters. Surface temperatures of between 80 and 95.7 °C have been recorded along the Nakaporon fault zone where geothermal activity is highest. Secondary activities occur over a broad area around the summit

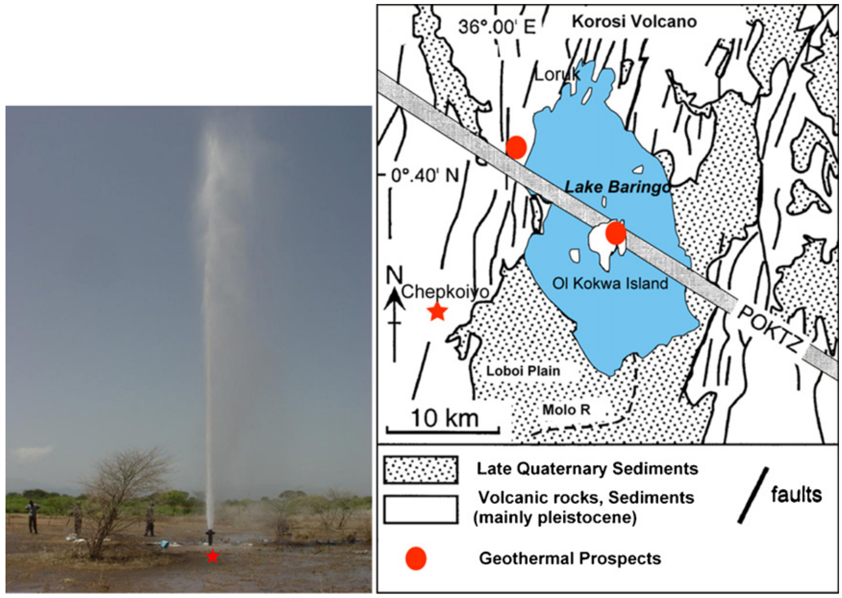

Fig. 6. *Left*: Chepkoiyo well (red star on the map) that erupted in April 2004 during community water project drilling. *Right*: Location of Geothermal prospects in the Lake Baringo area along the POKTZ: Porumbonyanza–Ol Kokwe Transverse Zone and on the western side of the lake along a major fault zone.
Source: Modified from Renaut and others [32].

with temperatures generally ranging between 40 and 70 °C. In the northern flanks along N–NNE trending faults ground fumarole temperatures range between 50 and 70 °C, in the lower northern flank controlled by N–NNW trending faults, temperatures range from below 40 °C to a maximum of 90 °C. Low temperature manifestations are found on the main basaltic feature fault zone on the southern flanks near the shores of Baringo with a maximum temperature of 48.7 °C. Isolated fumaroles occur SW near Loruk within lavas of Baringo Trachyte [9].

In Chepchuk, fumaroles and hot ground have temperatures ranging up to 96 °C in the northern part along N-trending faults parallel to the main Nagoreti fault. Surface manifestation is confined to an area of about 3 km^2 [36]. Anomalous ground temperature also occurs in the caldera floor.

Gas geothermometry based on H_2S indicates reservoir temperatures of >300 °C for Korosi geothermal prospect while Chepchuk is estimated to have intermediate temperatures. The main heat source appears to be located in the northern part of the volcano. Hot grounds and fumaroles in Korosi and Chepchuk cover about 45 km^2 [35] (Fig. 7). The current potential for geothermal development for Korosi is estimated at 450 MWe while Chepchuk is 100 MWe [30].

2.4.4. Paka prospect

Surface geothermal activities manifested in the form of fumaroles, hot grounds and hydrothermally altered rocks are widespread within the summit caldera and on extensive portions of the northern flanks of Paka volcano [9,38] (Fig. 8). Geothermal activity is most intense within the caldera with the hottest ground and strongest fumaroles located on the SW rim of the cone.

Intense geothermal activities also occur in the eastern crater with temperatures between 90 and 95.9 °C. Less intense geothermal activity occurs on the western side of the same crater with temperatures ranging between 40 and 80 °C. In the north eastern flanks, geothermal activity is concentrated along three northerly trending linear zones marked A, B and C in Fig. 8. Maximum temperatures recorded along Zone A is 96.1 °C, and Zone B, 90–96.1 °C decreasing towards the north to temperatures between 46 and 93 °C. In Zone C, activity is manifested in patches of hot ground with weak to moderate strength fumaroles with a temperature range of 35.5–96.3 °C. There is a general decline of activity towards the northern lower grounds. Activity on the western flanks is controlled by NNE trending zone with recorded hot ground temperature ranging between 48 and 88.9 °C increasing towards the caldera. In the southern flanks, patches of hot ground with temperature ranging from 42.7 to 77.5 °C occur [38].

The geothermal manifestations cover an area of 45 km^2 indicating a large heat source under the volcano where the hottest fumaroles occur. Fluid geothermometry indicates a possible reservoir temperature of >300 °C. Reservoir permeability is controlled by a NNE 4 km wide graben running across the volcano [39].

The maximum surface temperature recorded is 98.7 °C. The current estimated potential for geothermal energy is >500 MWe [30].

2.4.5. Silali prospect

Geothermal activity in Silali volcano is present in the caldera on the upper eastern flanks of the caldera floor concealed by a thin mantle of pumice on the NNE–SSW trending faults. Fumaroles on the eastern side of the caldera reach a maximum temperature of 96.8 °C. Steam from these fumaroles contain high CO_2 concentrations of up to 98% in the non-condensable gas fraction. The western half of the caldera appears to be inactive but hydrothermal alteration indicates past geothermal activity except outside the north western end where some activity occurs with temperatures of up to 57.6 °C [40].

Hot grounds and hot springs are found in Lorusio Kapedo, Akiloset and Kalnang'i all flowing towards Suguta River (Fig. 9).

The Lorusio springs occupy a small area of 2.5 km^2 located 60 km north of Lake Baringo and 10 km north of Kapedo. Surface manifestations are characterised by hot springs flowing eastwards between the steep western shoulder of the axial rift depression and the flanks of Silali volcano [9,41] at a rate of a few litres per second with a vent temperature of 40–82 °C. In outflow channels, the water temperatures are ∼30–68 °C. Most of the springs are ephemeral, and duration and volume of their discharge are unknown. The Lorusio hot springs form a small semi-permanent tributary of the Suguta River. A second small group of springs (∼35–55 °C) discharges along the western margin of Silali, east of Kapedo [42]. The perennial Kapedo hot springs on a 5 km strip along Suguta River are fed by subsurface flows from Lake Baringo [43,33]. The Kapedo springs discharge hot water of about 45 °C

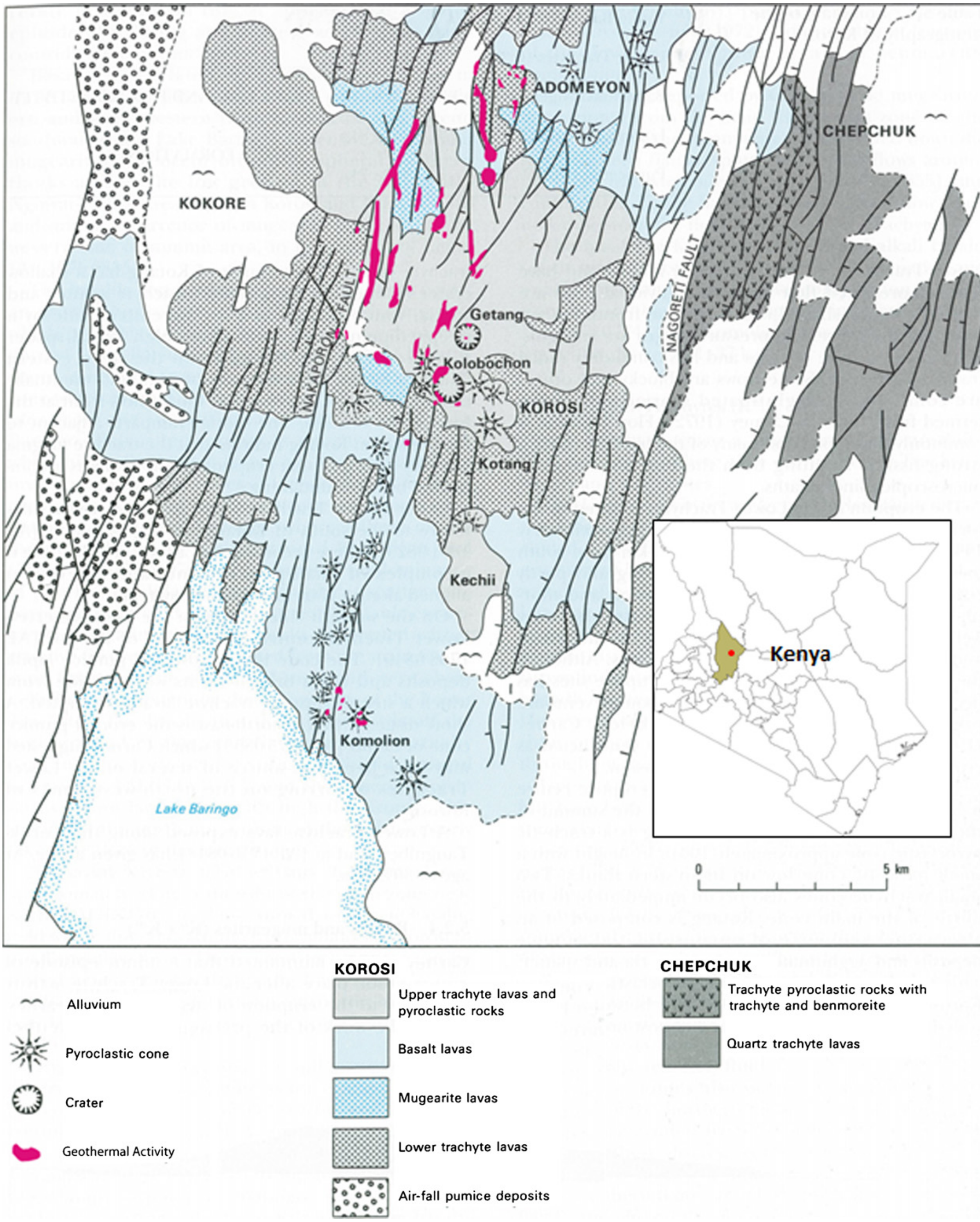

Fig. 7. Korosi and Chepchuk geology and geothermal prospects. Note the surface geothermal activity in red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)
Source: Modified from [37] and [9].

into Suguta River from a 30 m high water falls. Temperatures at the source of the spring range between 45 and 55 °C with innumerable springs flowing between Kapedo falls and the source yielding flow rates greater than 10 l/s cumulatively giving an estimate flow of 1000 l/s at the water falls [44]. Kapedo springs extend 1.5 km downstream of Suguta River with numerous springs and seepages with generally low flow rates of a few litres per second and a temperature range of 42–45 °C decreasing to 32 °C just before Lorusio.

Cool and warm alkaline springs occur around the periphery of the northern flanks of Silali at Akiloset and Kalnang'i draining into Suguta River with a temperature range from ambient to maximum of 38.2 °C [40,38].

The Silali geothermal prospect has the largest hot springs in the Kenya Rift system. Geothermometry indicates temperatures between 238 and 325 °C and an estimated potential of 1250 MWe [17].

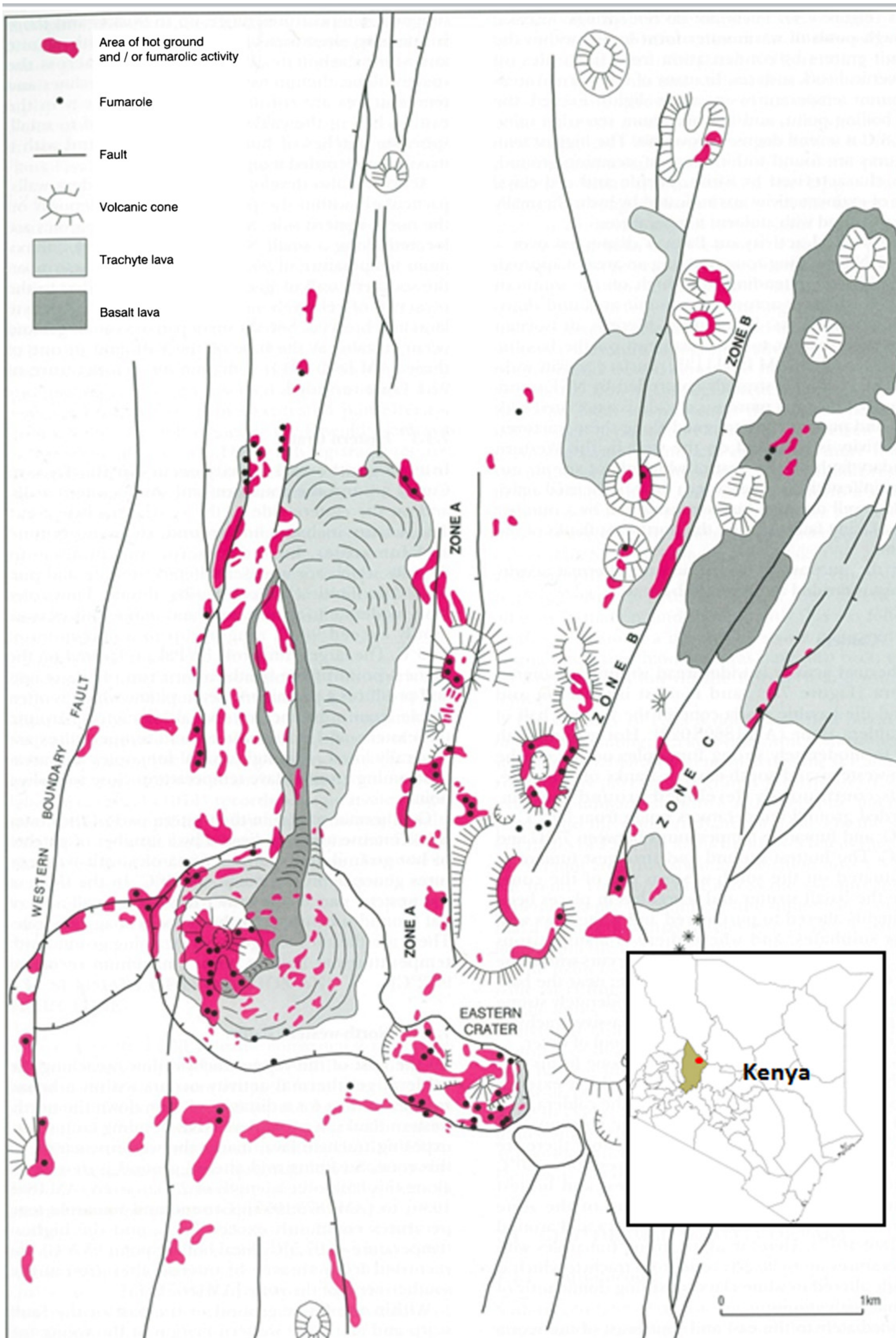

Fig. 8. Paka Volcano geology and geothermal prospect.

Source: Dunkley et al. [9].

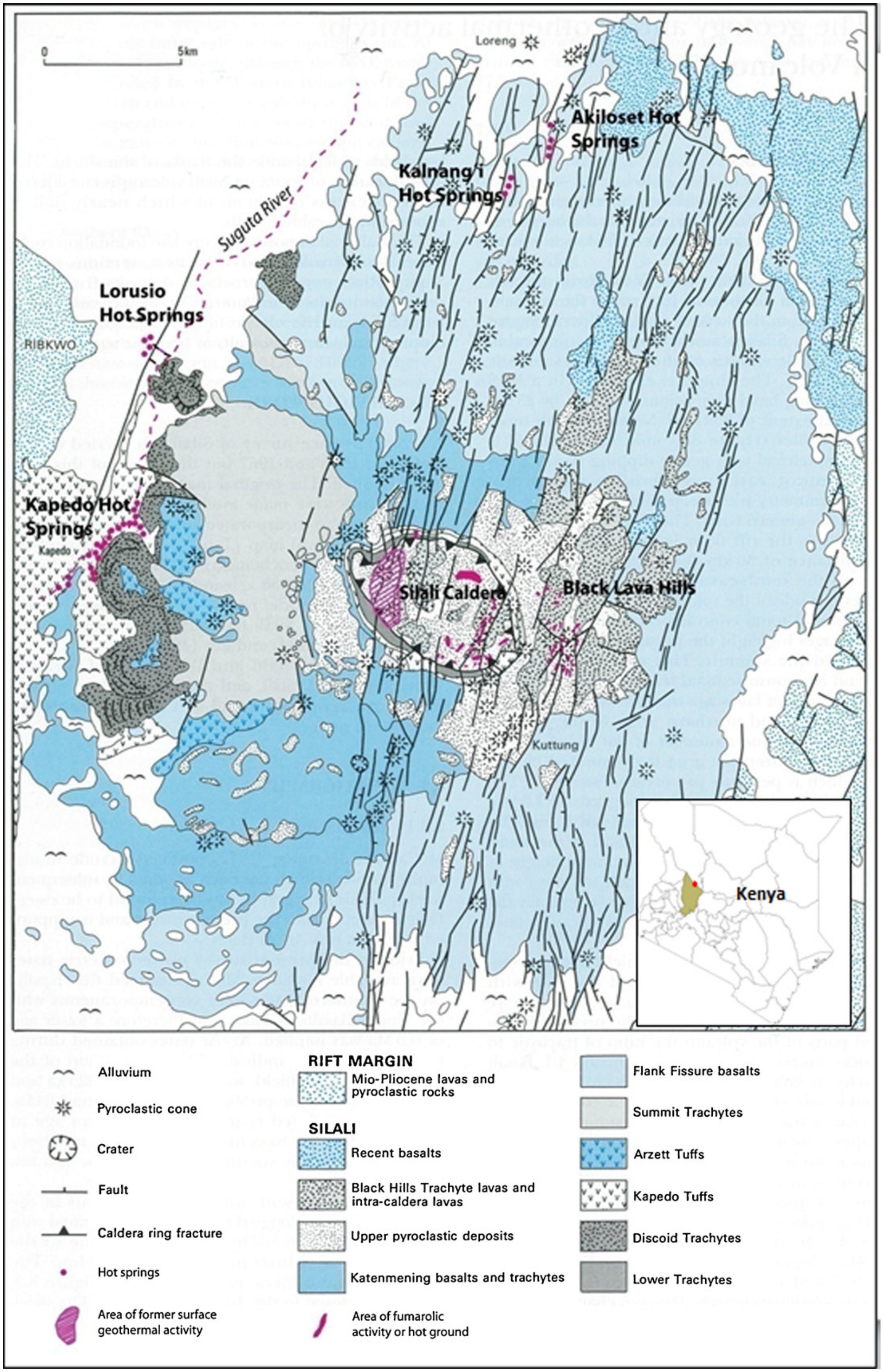

Fig. 9. Silali volcano geology, location of hot springs and surface manifestation.

Modified from [9].

3. Current utilisation of geothermal resources in the study area

3.1. Current non commercial utilisation

3.1.1. Religious and cultural use

The steam jets, geysers, hot springs and volcanic mountains in the study area were considered sacred among the Pokots, Njemps, Tugen and Endorois. Myths about the formation of these features are not properly documented but passed orally from generation to generation. Lake Bogoria is central to the Endorois religious and traditional practices. Community's historical prayer sites, places for circumcision rituals, and other cultural ceremonies are located around Lake Bogoria. The Endorois believe that the spirits of all Endorois, no matter where they are buried, live in the lake, and an annual festival is performed to appease them. The Endorois also believe that the adjacent Monchongoi forest is the birthplace of the Endorois and the settlement of the first Endorois community [45].

Ol Kokwa, where geothermal resources occur in Lake Baringo, means "meeting place" in the Njemps language. The thermal areas are considered sacred and occasionally used for religious ceremonies, circumcision, offering prayers during long droughts, age group ceremonies among others. Paka volcano is also considered sacred by the Pokots and Njemps, and is also an important dry season grazing ground. Rain making rituals take place at Nakurkur, the green area at the foot of Paka hills [46]. People who visit such places should be spiritually clean, or according to local belief, risk getting burnt by the hot surface thermal features.

Silali caldera is also considered sacred and a strategic hideout for stolen livestock among the Pokots.

3.1.2. Treatment of timber

According to the Endorois Chief at Kapkuikui, in the past, the hot springs were used by people of "Maji Moto" of Lake Bogoria for treatment of timber for construction of houses. The timber was left in the hot spring for about 3–4 days after which it is strong, durable and cannot be eaten by termites. However, since the area was gazetted for conservation under Lake Bogoria National Reserve, this activity has stopped.

3.1.3. Human and animal health

The hot springs and steam jets in their natural form are used by the community and visitors as saunas. This type of use is also dominated by Asian visitors who travel to Bogoria specifically for this purpose. Despite the poor infrastructure to Kapedo, some tourists' bathe directly in Kapedo falls hot springs in the northern part of the study area. The area also provides salt licks for de-worming and treatment of coughs in animals.

Livestock bathing pools for skin diseases and external parasites can be set up for local as practiced in Tibet area of China [47].

3.1.4. Provision of water

Some warm springs (<40 °C) provide water for domestic purposes despite the high fluoride and sodium contents. One such example is Lorwai spring, where water is pumped using solar electricity by a private developer for his own personal use and that of Kapkuikui community through a pipeline and communal tap. This has reduced the distance of community access to water by a total of 26 km [48]. Unlike the community in Ebburu in Naivasha, the local community does not tap geothermal steam condensate for domestic or livestock watering.

3.1.5. Boiling of eggs and meat

The hot springs in the study area are used by the locals for boiling of eggs and meat. Boiling and selling of "geothermal eggs" to tourists is practiced at Lake Bogoria (eggs are boiled on order) (Fig. 10). Some locals also place meat in a plastic bag, and boil it in the shallow hot springs.

Fig. 10. Egg boiling in a geothermal hot spring at Lake Bogoria.

4. Potential of commercial utilisation for adaptation to impacts of climate change

Adaptation is defined as, "Adjustment in natural or *human systems* in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities". Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation (IPCC 4AR, 2007: Annex 1 – Glossary) [49]

Geothermal resources in the study area have not been utilised for commercial gains apart from the bathing at Lake Bogoria Spa Resort. This section focuses on the potential for both direct and indirect utilisation of geothermal resources in climate vulnerable sectors of the study area using local resources to improve adaptive capacity of local people.

While using geothermal applications, it is necessary to consider the water chemistry, pH, suspended solids and heavy metals in the fluid depending on the temperature and utilisation scheme.

Application of geothermal energy for direct use is best done within a radius of 50 km from raw materials for industrial or recreational uses. Transporting material over long distances may be uneconomical as geothermal hot water is best used on site for optimal efficiency [50]. Steep topography on either side of the study area (e.g., Tugen hills and Laikipia escarpment) also delineates physical extent of use. The potential of utilisation in adaptation described below is based on natural resources and raw materials that can be obtained locally and are familiar to the local people.

Potential utilisation schemes include: bathing and spa, geothermal tourism, electricity for water lifting, crop irrigation, greenhouse farming, and industrial processes such as, meat processing (beef, mutton, lamb and chicken), milk processing, crop and vegetable drying, juice and wine waking, processing of the naturally occurring *Aloe turkanensis* and *Aloe secundiflora*, processing of honey and wax products, fish processing, and unexploited minerals. Other potential activities not discussed in detail include wool-washing, carpet and fabric dyeing and pottery production among others. The above can be achieved using geothermal resources described in Section 3 of this paper.

4.1. Sustainable tourism and spa

4.1.1. Bathing/spa pool

The study area has the potential for mineralised thermal water baths, as well as steam, and mud baths which can be marketed

Fig. 11. Lake Bogoria Spa using water directly from a hot spring.

as a new brand of tourism to complement wildlife tourism that is already established in other parts of the country. Increase in health spas will lead to increase in both domestic and international tourism which will in turn increase the demand for services and infrastructure.

Development of spas requires hot water between 30 °C and 40 °C which is available and can also be obtained in a cascade system. This application can also rely on shallow wells with a temperature range of >77 °C which can be used in a cascade before it flows through the pools and baths [51]. The wells can also supply hot water to hotels for use in laundry, heating of sauna baths and use in bathrooms.

The Lake Bogoria Spa Resort, commissioned in 1992, draws its water from a nearby hot spring with a temperature of about 38 °C and flows into the thermal pool through a small open water channel (Fig. 11). The resort does not use geothermal water for other hotel services like laundry, water heating, and space cooling and heating despite the potential and close proximity to the resource. It can also generate electricity using a binary plant instead of depending on the unreliable electricity supplied from outside the region or standby diesel generators [52].

This type of use can be upscaled in the entire region.

4.1.2. Sustainable tourism

The mid and north rift tourism circuit is not well developed and commonly referred to as *a sleeping giant* [53] due to the lack of infrastructure (e.g., electricity and roads), other essential services and poor security which have reduced accessibility to potential sites.

The study area has Lake Baringo and Bogoria National Reserves which are Ramsar sites and community conservancies such as Ruko (to the immediate north of Lake Baringo), Kaptuya in Churo, and Logis in Kapedo. The surface thermal manifestations are also a major attraction (Fig. 12). The Lake Bogoria receives about 500,000 visitors and generates about KES 18 million in revenue in a normal year but has the potential to generate more with better infrastructural development [54].

The few existing facilities depend on unreliable electricity and diesel generators and can only sustain limited tourism. Expansion of tourist services into the remote areas will be met through energy services from planned geothermal development, and by providing hot water for use in hotels through direct utilisation [55].

4.1.3. Link to adaptation

Though drought has a negative impact on wildlife, geothermal tourism is not affected by drought. For instance, in 2006, a drought year, the Lake Bogoria Reserve received about KES 18 million (approximately USD 231,000) from park visits. The development of tourism infrastructure using geothermal resources will:

- lead to improvement in tourism-linked service sectors, including transport, communications, water supply, energy and health services;
- reduce consumption of fossil fuels currently used by hotels and thus reduce CO_2 emissions;
- create direct and indirect employment in tourism facilities and services (e.g., 95% of people employed in the two reserves and conservancies are locals and paid from the revenue);
- increase in income from the main tourist activities like cultural exhibitions, selling of cultural artifacts, community camp sites;
- increase in revenue from tourism for community development projects (e.g., revenue from Lake Bogoria and Baringo is shared on a 50/50 basis (6% of which is given back to the community through development projects out of which 2% goes towards bursary in the form of payment of school fees for the needy, while 4% goes to projects such as schools, water, health facilities such as, maternity wing of Loboi health centre) [56] and;

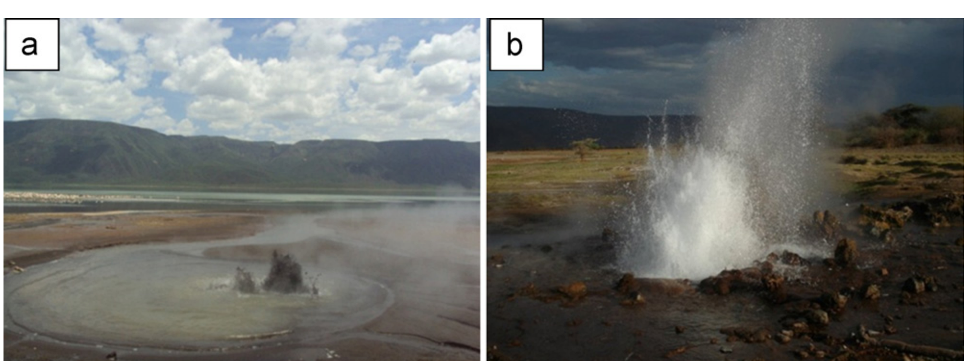

Fig. 12. (a) Mud pool and (b) geyser at Lake Bogoria.

Fig. 13. Pumping of borehole water using solar energy at Kampi ya Turkana.

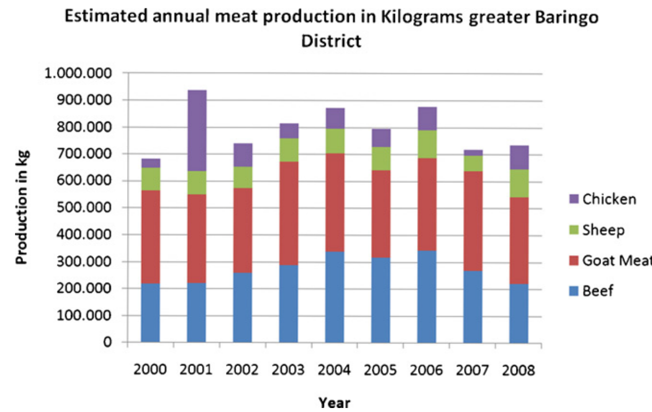

Fig. 14. Annual meat production in kilograms.
Source: Annual District Livestock Production Reports [63].

- additional income through local goods and services provided by geothermal development.

An increase in tourism will have a spin-off effect in the local economy and improve adaptive capacity of the people.

Unsustainable development of geothermal resources can lower the water table, lead to disappearance of the existing surface thermal manifestation and reduce revenue from tourism.

4.2. Improved water lifting and distribution

Surface water sources, most of which are seasonal, and a few boreholes are used to supplement water for domestic and livestock use. Improved ground water lifting provides an alternative means of meeting the water requirements. The current popular ground water lifting methods include hand pumps, diesel driven pumps, and a few solar (Fig. 13) and wind pumps, respectively.

Water pumping for the large herd of livestock kept by the pastoralists is energy intensive. In East Pokot, almost 50% of the boreholes are diesel driven. The diesel powered pumps consume about 10 l of diesel per day on average but much higher in the dry season when surface sources run dry [57]. According to revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, burning 1 kg (1.176 l) diesel emits 3.2 kg of CO_2. Based on an average day, one borehole burns approximately 30 kg of CO_2/day which translates to about 9900 kg of CO_2 annually. The diesel is also too expensive and sourced from far, at distances ranging between 50 and 150 km from Marigat fuel station. Other problems include regular cash collection to buy fuel, expensive parts, noise, and emission of CO_2, transport cost and delays, and regular maintenance checks which must be done by skilled personnel.

Electricity from geothermal or other reliable sources is needed for the dry season water pumping to substitute diesel pumps and supplement solar powered pumps to provide enough water for domestic and livestock use especially during the dry season. Adequate water resources are also needed for the development of geothermal resources and use in adaptation schemes proposed in this article.

4.2.1. Link to adaptation

Improved water lifting services brought by grid and off-grid decentralised systems will increase the amount of water available during drought for livestock, domestic and agricultural use; reduce loss of livestock, thus improving food security and income; replace diesel pumps and offset CO_2 emission; reduce water related migration and conflict; improve hygiene and better health; and reduce work load and time spent by women, men and children in search of water for domestic and livestock uses.

Unsustainable abstraction of ground water resources due to improved pumping can lead to decline in groundwater table and must therefore be regulated through water abstraction permits.

4.3. Meat production and processing

4.3.1. Current status and potential for geothermal use

Livestock losses during drought range between 50 and >90% [58–61] depending on the duration of the drought, number and type of livestock (goats are more resistant) and government interventions. During the 2008/2009 drought, households lost up to 90% of their livestock [62,12]. Lack of in situ facilities for slaughter, meat processing and preservation, poor market channels for pre-drought sales and poor infrastructure, further reduce the adaptive capacity of the people.

Fig. 14 shows meat production between 2000 and 2008 under current conditions without improvement and value addition. Annual average production of meat in the study area is estimated as: beef 300 ton/year, mutton 350 ton/year, lamb 100 ton/year, and chicken 100 ton/year. Meat production can be increased with better facilities and improved infrastructural development.

Slaughter house/slabs in Marigat can only slaughter 48–50 goats/days to meet the local demand (Fig. 15). Such facilities cannot meet demand beyond the local area without substantial improvement leaving the pastoralist at the mercy of middlemen who buy the animals and sell in Nakuru where modern slaughter houses and ready meat market exists.

Fig. 15. Marigat slaughter slabs and “house”.

Traditional and modern meat preservation technologies are required in reducing the impact of drought. Though small quantities of meat are dried by smoke at household level, bulk drying for later use or sale in the event of a drought cannot be achieved without proper energy infrastructure. Technologies for drying meat using local energy sources such as solar and geothermal can be disseminated at small scale and managed by organised community cooperatives. Setting up of community based meat drying facilities such as, batch dryers where groups of local people or cooperative can bring their meat for drying and storage to avoid livestock mortality and secure food for consumption and sale can be a significant move towards adaptation in food security. The facilities can be simple and custom made to dry several products and should supplement the Kenya Meat Commission facilities.

The Kenya Meat Commission (KMC) can also set up satellite slaughter houses in the remote areas close to geothermal resources where animals can be sold directly to slaughter houses and meat processing plants throughout the year at fair prices to reduce losses incurred by pastoralists [64].

Thermal energy requirements for small scale non-industrial slaughter houses for processing of red meat with example from Poland are as follows: slaughter 50 kWht/ton of carcass, cutting and deboning 12 kWht/ton of carcass, processing 200 kWht/ton, rendering 333 kWht/ton input, other 11 kWht/ton [65], which is an average of 600 kWht/ton.

The plant requires hot (85 °C) and warm (45 °C) water for knife and equipment sterilisation, cleaning and personal hygiene. Hot and warm water requirements are limited to cleaning time. The amount of hot water extracted depends on the size of the processing plant [66]. Lund [51] suggests 105–120 °C for sterilisation in meat packing and food processing.

Approximately 60–70% of electrical energy use in meat processing plants goes to refrigeration especially in hot weather. The rest of the energy is consumed by motors, air compression and lighting. Most industrialised meat processing plants have a peak electrical load of less than 5 MWe [66]. Waste from meat processing plant can be channelled into a biogas plant to provide electricity, reduce operational costs and create more jobs.

4.3.2. Link to adaptation

Improved meat processing or drying can lead to early conversion of livestock into preserved food or fiscal assets at onset of drought, thus improving income base, food security and adaptive capacity of the pastoralists. Increased and effective livestock vaccination resulting from availability of electricity for cold storage in areas which were previously inaccessible, will reduce livestock diseases and mortality and build resilience to drought. Migration, conflicts and the work load borne by women when men leave the home in search of water and pasture or wage employment will also decline.

Abattoirs use a lot of water for cleaning and other purposes and can undermine adaptation efforts. Water conservation, waste and waste water disposal methods and sanitary measures must be properly taken into account when planning for the meat processing plants.

4.4. Small scale liquid and dry milk processing

4.4.1. Current status and potential for geothermal use processing and pasteurisation

Annual milk production from cows, goats and camels is summarised in Fig. 16. Milk availability declines with drought. Milk is an important part of the pastoral diet; hence the need for preservation to ensure constant supply at reasonable prices if produced and preserved locally. A Zebu cow (indigenous species) produces approximately 1–2 l of milk per day while a hybrid cow produces

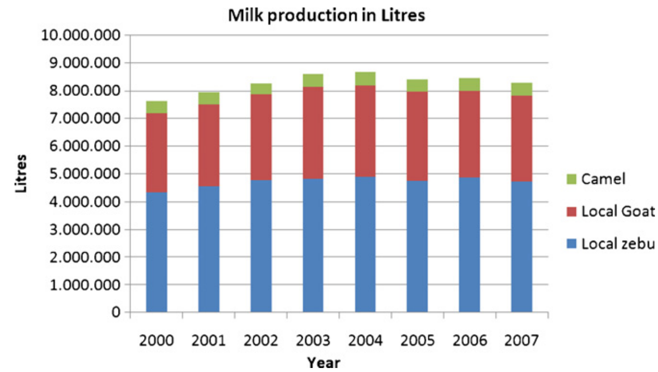

Fig. 16. Annual milk production from goats, camel and cows.
Source: Extracted from Annual District Livestock Production Reports [63].

8–10 l and a cross breed of the two produces 4–6 l per day [67]. Delivery of small quantities of milk can be hampered by long distances between production areas and markets, bad roads and high ambient temperatures. Development of geothermal resources in remote areas can resolve the above.

Geothermal heat can be used in pasteurisation, dry powder, UHT, evaporated and condensed milk. Thermal energy requirements for milk pasteurisation including chilling is 855 kWht/ton [68], 610 kWht/ton for full cream milk powder, 190 kWht/ton for UHT and evaporated condensed milk 355 kWht/ton [69]. Milk processing can be achieved using low to medium temperature geothermal resources 65–85 °C for sterilisation and evaporation (powder milk) to retain natural taste [70,71]. Medo-Bel Creamery in Klamath Falls, Oregon, used geothermal heat in its milk pasteurisation process for about 50 years. The minimum temperature required was 78 °C for 15 min [72].

Electrical energy for chilling milk 0.5–100 l per day is estimated to be 25–30 kWhe/ton net and between 85 and 105 kWhe/ton gross (gross includes secondary activities). This includes refrigeration units, milk agitator, power equivalent for water supply and heating or pumping systems which is typical of small processing plants that receive between 0.5 and 100 l per day. Refrigeration consumes about 40% of total electricity use [69,73].

Improvement in milk production and availability will improve nutrition, food availability and income from the sale, and reduction in high season wastage. Though water will be used for cleaning equipments, no maladaptation was identified in milk processing.

4.5. Crop production and agro-industry

This section focuses on use of geothermal in enhancing dry season irrigation, greenhouses, crop drying and food and wine processing to improve income and food security.

4.5.1. Potential for geothermal electricity use for dry season irrigation

In the 19th century, traditional irrigation scheme flourished in the Njemps plains (south of Lake Baringo) and provided grain for Swahili trade caravans, which first reached the region in the 1840s and practiced barter trade with the locals. The Njemps plains was considered most reliable source of grain for the traders and pastoralists [58]. The Njemps plain is today part of the Perkerra Irrigation Scheme, which was constructed by Mau Mau detainees in the 1950s. Traditional and modern irrigation schemes exist and can be improved.

Irrigation at Perkerra is overseen by the National Irrigation Board, Chemeron scheme by Kerio Valley Development Authority (KVDA). Community based schemes include Kapkuikui, Eldume, Nyoro, Kamoskoi, Mukutani, Kiserian, Sandai, Salabani, Endao,

Fig. 17. (a) Damaged irrigation water canal at Perkerra Scheme in Marigat. (b) Mango trees and vegetable cultivation under open canal irrigation. (c) Greenhouses at Oserian Company in Naivasha, Kenya, growing flowers and horticultural crops.

Losekem, Lamalok and among others, most of which have collapsed using both seasonal and permanent river sources.

Agriculture in the area is characterised by inadequate rainfall, small farm sizes, frequent droughts, soil erosion and use of poor irrigation techniques. The reduction in area under irrigated agriculture caused by water shortages and siltation has led to loss of livelihood and exacerbated food shortages.

Only 1500 ha out of irrigable 5000 ha is currently used. Groundwater can irrigate up to 40% of irrigable land (>5000 ha) if used on a small scale of at least ¼ ha per household in the irrigable areas using water conserving techniques. The groundwater potential is adequate to meet both domestic and livestock needs, as wells boost irrigation needs [57]. Improved access to electricity can improve the volume of water pumped for dry season irrigation and ensure all year round food production. According to Pandey [74], low temperature geothermal springs can also be used to energise solar pumps. Geothermal water is directly used for irrigation in southern Tunisia after cooling [75]. This type of application could lead to soil and water contamination with heavy metals and can only be done where the water chemistry is suitable. Most of the warm and hot springs in the study are highly mineralised and can only be used for domestic chores and not irrigation (without extensive research). Pumping water for irrigation must therefore be limited to cold surface and groundwater sources where feasible.

4.5.2. Application in greenhouses to improve food security

Crop production can be improved in greenhouses with or without geothermal heating. Geothermally heated greenhouses provide a better option than the current inefficient outdoor irrigation practices. Greenhouses in arid lands reduce crop water requirements by reducing evapotranspiration by 60–85% compared to outside farming [76,77]. Greenhouse farming saves up to about 20–25% of water compared to open drip irrigation [78] (Fig. 17).

The CO_2 in geothermal fluids is collected mostly in metal gas bottles and in a few cases piped into the greenhouses. The CO_2 released in the greenhouse is beneficial to the plants as a growth stimulant. Studies have shown that increase in CO_2 from a normal level of 300 ppm to approximately 1000 ppm can raise crop yields by up to 15% [79] and also improve quality.

Oserian Development Company Ltd. in Naivasha, Kenya, is using one geothermal well (OW 101), with a capacity of 16 MWt to heat 50 ha greenhouses for growing roses. The well has a combined mass flow rate of about 50 ton/h with an average temperature of 136 °C. Additionally, the company generates 3.21 MWe from two wells. The use of geothermal in heating the greenhouses to control humidity at Oserian has eliminated the use of fungicides and reduced maturing period of flowers by three to four weeks. Geothermal heat is required for 6–8 h a day (during the night) throughout the year with an annual consumption of about 90,000 kWht/m^2 [80].

Experience from geothermal application in greenhouses at Oserian can be used in the development of small scale greenhouses in the study area especially within the existing irrigation schemes. Greenhouse farming should be accompanied by a shift from open canal irrigation to more water efficient methods to improve the quantity and quality of food grown per hectare. One or two geothermal wells can be drilled specifically for greenhouse application to enhance food security in the existing irrigation schemes.

A proportion of the money currently used in providing food aid and other emergency drought response services can be used in setting up small greenhouse farming schemes in addition to enhancing other long term interventions like promotion of drought resistant crops. To improve economics of geothermally heated greenhouses, other activities like fruit and vegetable drying, cool storage and others should be considered. Geothermal utilisation in greenhouses is practiced in Kenya, Italy, Iceland, US, among others for commercial purposes and can also be used to improve food security.

4.5.3. Crop and vegetable drying/dehydration

The ability to dry crops and vegetables is crucial, especially after abundant harvests to avoid wastages and improve availability of nutritional food during drought and throughout the year. The drying heat may be supplied by convection (direct dryers), conduction (contact or indirect dryers), radiation or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field. More than 85% of industrial dryers are of the convective type with hot air or direct combustion gases as the drying medium. The heat supplied must be equal to the heat required for evaporation. The heat should not be more or less than the required amount for evaporation to avoid hardening, discolouration or other unsuitable outcomes [81].

Increased greenhouse production can be accompanied by geothermal application in crop drying. Agricultural drying using low to medium enthalpy geothermal resources has the highest potential for industrial application. Geothermal drying of fruits and vegetables can be accomplished with water temperatures as low as 55 °C.[3] In geothermal drying, electric power is used to drive fans and pumps using continuous forced-air processes by passing heated air over the food making it dry uniformly. Drying can be done in a conveyor belt or batch dryers and can either be industrial or very small basic units operable by farmers. Heat for drying can be obtained from geothermal well or by waste heat recovery from an existing geothermal plant [82]. To evaporate 1 ton of moisture requires 2 tons of steam and therefore the requirement for steam can be calculated using the moisture content of the product [83]. According to Lund [68], experience from geothermal utilisation in the US for drying using a single conveyor belt requires about 170,000 kWht/ton (dry weight).

In the past, chilli drying was done in the sun on corrugated iron slabs (Fig. 18). This can be replaced by geothermal drying for better quality and preservation.

[3] http://www.techfest.org/initiatives/prayaas/energise/Geothermal_dehydration.pdf.

Fig. 18. Corrugated iron sheet stands in Marigat centre previously used for sun drying of chili but now drying of maize and other crops since production of chili stopped.

Methods used in tomato drying can be borrowed from the Greek experience where 59 °C geothermal hot water is used to dry 14 kg of tomatoes per hour. Drying requires mild temperatures of 45–55 °C to retain the nutrients, aroma, flavour and colour of the tomatoes and most dried vegetables [84]. The thermal energy requirement for tomato drying in the case of northern Greece is 1450 kWht/ton (wet weight) and 15,000 kWht/ton (dry weight), for onion drying in Nevada is 165,000 kWht/ton (wet weight) and 1,000,000 kWht/ton (dry weight), and 136 kWht/ton for rice drying in Macedonia [68].

The Perkerra irrigation scheme produces pawpaws, mangoes, onion, chilli tomatoes, oranges, and water melons and other fruits and vegetables which go to waste due to inadequate storage and processing facilities. Geothermal energy can provide the energy needed for these processes and ensure sustained demand and supply of food and income throughout the year.

4.5.4. Juice making and canned preservation

The collapsed Kenya Wine Agency Limited (KWAL) food processing factory which opened in Marigat in 1982 bought pawpaws from farmers and produced juice and wine for local and international markets. Farmers at Perkerra still have pawpaw trees on about 50 acres without proper marketing avenues long after the closure of the factory, which used diesel for production. Wine and juice production can be revived with the use of geothermal energy in the region. The process for juice making involves heat treatment through short time exposure to high temperatures to denature proteins, reduce unwanted microorganisms and enhance aroma.

Geothermal resources with temperatures of 95–149 °C have been used in preparing juice, alcoholic beverages and processing of canned foods [85] and the same can be applied in the study area. Electricity for lighting, storage and packaging purposes is required.

4.5.5. Link to adaptation

Direct and indirect (e.g., electricity production) uses of geothermal will improve adaptive capacity of the local people by increasing crop production through improved water lifting and greenhouse farming, ensuring all year round farming, efficient drying of fruits and vegetables as well as processing and juice extraction thus ensuring increased food security, improving income from increased production and reducing malnutrition, infant mortality and improved maternal health.

Uncontrolled agricultural production can lead to over abstraction of water resources for irrigation and industrial processes if deliberate conservation efforts and use of drip irrigation are not applied. Growth in agricultural processes will require more energy. Cascaded use of geothermal resources can improve the efficiency of hot water use in agricultural processes and reduce over withdrawal of the resource.

4.6. Production and processing of aloe

Indigenous *A. secundiflora*, and *A. turkanensis* are considered a viable alternative source of income because they grow naturally in the lowlands, and are beneficial to soil conservation, as well as production of organic honey. Furthermore, the species do not require irrigation and yet remain underexploited. Aloe is listed as an endangered species under the Convention on International Trade in Endangered Species (CITIES) and must be processed from established plantations or certified Aloe Management Units. Aloe products at cottage industry and household level in the study area include products like soap, shampoo, lotion and sale of aloe bitter gum [86].[4]

Wood fuel is used in boiling aloe sap in the area. For instance, Baringo Bio-enterprise at Koriema in Marigat District (which closed in early 2010 barely one year after its commencement of operations) used about 40 kg of prosopis firewood to boil 100 l of sap for 3 h (Fig. 19). Packaging and labelling of the product were also done manually and hence the products could neither be certified by the Kenya Bureau of Standards nor sold at supermarkets or internationally. The factory was licensed by Kenya Wildlife Service (KWS) to harvest 30,000 l per year and was only achieving 7% of the target due to less mechanised methods of production [87].

Potential for direct use of geothermal energy in boiling sap will require >120 °C which is readily available. The hot water can also be used in downstream activities like sterilisation and washing of equipment. Electricity for lighting, computer data storage and labelling will increase efficiency and quality of the product.

4.6.1. Use of aloe gel as a scale inhibitor

The most common type of scaling in geothermal systems is precipitation of calcium carbonate and amorphous silica scaling. To avoid scaling, brine pH modification is done through acid treatment, polymerisation and use of chemical inhibitors. Scaling can reduce formation porosity and permeability, block pipes and equipment used in transmission of geothermal fluids [88].

A recent invention which is still under patent application discusses the use of aloe derived scale inhibitor. According to Viloria et al. [89] (the inventors), the scale inhibitor comprises aloe gel

[4] Jane Cherono 2010 secretary of Emukwen women group from Sandai which produces 210 pieces of soap/week and also produce liquid soap both sold locally at KES 50/l.

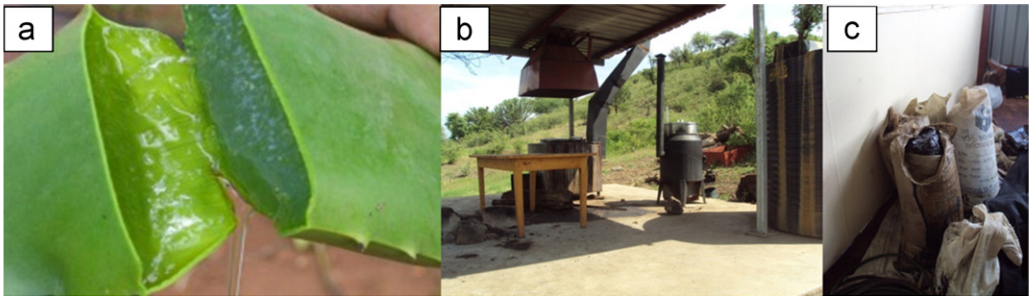

Fig. 19. (a) Flowing sap from aloe plant. (b) Wood fuel stove for boiling sap at the Baringo Bio-enterprise. (c) Ready aloe sap in storage waiting for sale after boiling (black and hard). Sap is used for making soap and other aloe products.

dissolved in water at concentration of about 5 and 50% of weight. The aloe gel has polysaccharides from whole aloe vera leaf or plant. The polysaccharides are then solubilised in water between 60 °C and about 90 °C and have hydrocarbon chain structure with carboxyl and alcohol that interacts with divalent ions like Ca^{2+} and Mg^{2+}. According to the findings of Viloria et al., hydrolysis favours interaction with ions in the solution increasing its efficiency as scale inhibitor. The inhibitor is also thermally stable up to a temperature of about 125 °C. The plant inhibitor is cheaper as it is not a chemically synthesised compound, it is biodegradable, and boosts the local agricultural economic sector. If this technology is tested and proven it can increase the demand for aloe derived scale inhibitor in hydrocarbon [89] and geothermal systems.

4.6.2. Link to adaptation

The aloe plant is drought tolerant, grows naturally, has an already established market, and can provide an alternative source of income. It has the potential to contribute to household food security through increased economic security, and should not threaten food production due to its ability to grow naturally in harsh environments. Though aloe production in the study area is limited to small women groups and the Baringo Bio enterprise group, it can be scaled up with improved energy and production services.

Expansion of aloe farming and production of sap using fuel wood will increase the demand for fuel wood and may lead to environmental degradation.

4.7. Processing of honey and beeswax

Traditional bee keeping is among the four most important current economic activities. Despite this, honey and wax production remains underexploited, many hives are not harvested, and honey is stocked in houses for years. Households own between 30 and 300 hives producing organic honey from acacia, prosopis and aloe plants. Honey is sold by organised groups and individual vendors. Existing organised groups producing honey and wax at cottage industry despite making some improvements and selling honey in jars, have not met the requirement of the Kenya Bureau of Standards for honey referenced KBS-KS05-344:1994 due to inadequate funds for investment in modern processing and packaging equipments. In contrast, individual vendors sell honey in unsterile liquor bottles by the roadside at a cheaper price (Fig. 20). Average honey production from the Baringo county is approximately 350,000 l per year generating revenue of approximately KES 25 million. Wax production is still low and approximated at 50 kg per year [90].

4.7.1. Honey processing

Current honey harvesting and processing methods do not aim for pure products. Such methods include the application of heat to hasten the flow of honey from the comb either by using firewood, direct heating over open fire, warming in the sun, warming the honey in a water bath (between 35 and 50 °C) or leaving the honey to seep out from the comb. Uniform heating of a large amount of honey at the right temperature can be difficult without the right form of energy. The temperature required for honey extraction should not exceed 71 °C [91,92]. Use of high temperature heat sources like open flames or a boiling water bath may quickly lead to local overheating and cause smoking and burning of the product. There are a few manually operated centrifuges equipped with a hand crank or a bicycle chain also used in extraction of honey. Honey can be sold as organic honey or for use by wineries, or in cosmetics and pharmaceutical products.

Honey processing facilities include heating and cooling units, filter presses and pumps that deliver the finished product to the packing line, including automatic sticking of pre printed labels on finished products to meet Kenya Bureau of Standards requirements. Low enthalpy geothermal resources can be used in honey processing as they provide uniform temperatures and can thus be controlled. Required temperatures range from 40 to 70 °C. Hot water of about 77 °C can be used for sterilisation of packaging bottles [51].

4.7.2. Beeswax processing

Beeswax processing involves melting of bee combs, sieving and cooling molten wax. Beeswax in heavy combs softens at temperatures above 40 °C [91]. Practiced processing methods involve mixing the combs and water in a sufuria (aluminium pot) and heating it using firewood. Wax melts at about 62–64 °C [93]. Wax is also extracted manually by squeezing in cotton bags and in a few places using a solar wax smelter, which is limited by hours of sunlight. The steam extraction method has not been tried in the study area.

Wax products include candles, royal jelly, furniture and shoe polish: other products can be manufactured in the same plant using geothermal low enthalpy resources. Geothermal energy can also be used in sterilising equipments and providing electricity for labelling, lighting and computer data storage.

4.7.3. Link to adaptation

Despite the existence of some honey marketing organisations such as, Honey Care Africa, which buys the raw honey in bulk, the potential for honey production has not been fully harnessed. Improvements in honey and wax processing and marketing will improve household income and improve food security. Honey is also used as a crucial food supplement during droughts.

4.8. Fisheries

Fish species composition in Baringo include *Oreochromis niloticus* (80%), *Protopterus aethiopicus* (7.6%), *Clarias gariepinus* (8.9%), *Barbus gregorii* (3.1%), *Labeo cylindricus* (0.1%) among others [94]. The current decline in commercial fish catch is caused by to extreme drought events, siltation of the lake, poor fishing methods,

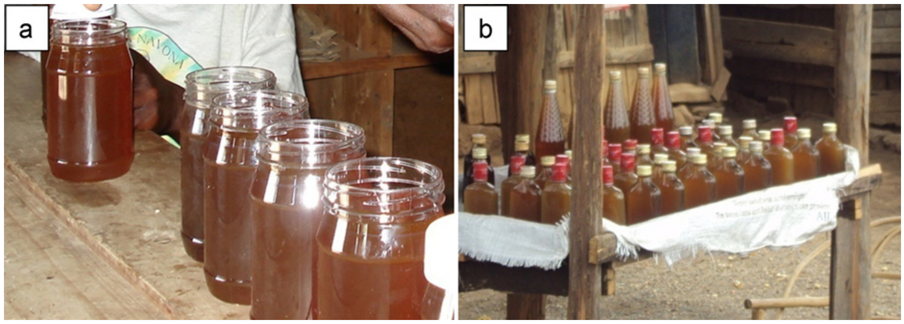

Fig. 20. (a) Comparison of containers of honey sold by organised groups or cooperatives in new jars and honey sold by individuals in unsterile liquor or other bottles. (b) Both have not met the requirements of the Kenya Bureau of Standards.

seasonality of rivers, damming and diversions (except in flood years) [95,96].

To supplement lake fisheries, fish farming is being introduced based on assessment done by the Fisheries Department under the government economic stimulus package. The high potential fish farming areas in Fig. 21 [97], have no access to electricity, but happen to coincide with high and low temperature geothermal resources. About 16 community based fish ponds (earth ponds[5]) have been successfully established at Emsos south of Lake Bogoria and about 650 in the adjacent Subukia through World Wildlife Fund (WWF), Community Development Fund (CDF), Kenya Agricultural Research Institute (KARI) and relevant government ministries to supplement diet and improve food security [98].[6]

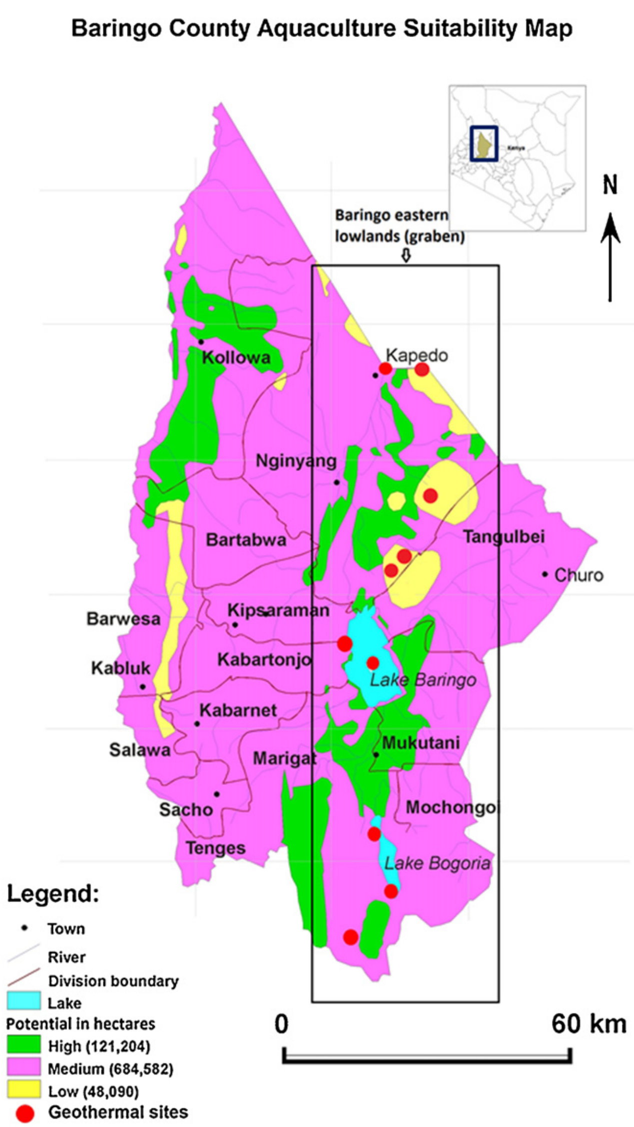

Fig. 21. Baringo county aquaculture suitability map. *Source*: Modified from Fisheries Department [99].

Unlike in temperate countries, tropical fish may not need geothermal heating to grow. For example, Tilapia grow best at 28–30 °C [100] but will require geothermal heat for fish processing and drying as well as electricity for refrigeration, chill rooms, ice making and lighting. Geothermal hot water is also required for sterilising equipments. Current fish preservation methods include smoking using firewood (widespread), sun drying, salting and frying. Geothermal equipment designed for drying fish can also be used for drying agricultural industrial products [101].

Fish drying using geothermal resources requires about 96,000 kWht/ton [68]. The advantages of using geothermal energy in fish processing and preservation over current practices include consistency in quality and content, less contamination and reduced consumption of fuel wood and associated health and environmental impacts.

4.8.1. Link to adaptation

Improved fish drying will lead to a reduction in use of fuel wood for smoking and drying, and wastage through provision of cold storage facilities, and an increase in local income, food security and nutrition.

The main drawbacks of earth pond fish farming are rapid siltation of the ponds which require regular maintenance (de-silting), that they are seasonal (depend on seasonal rainfall) and require water retaining soils (preferably soils with high clay content). The non-fish eating culture of the pastoralists is however an issue. High evaporation rates with long dry spells can also reduce the productivity in the fish farms as most of the ponds remain dry during drought and long dry spells. The ponds can also be a breeding ground for mosquitoes especially in the wet season; however, most tropical fish eat mosquito larvae hence reducing the potential increase in mosquitoes and malaria.

4.9. Mining

4.9.1. Mineral extraction and CO_2 mining

Movement of superheated water and gases through the rock leads to precipitation of different minerals at different locations. Hot gases escaping through vents also bring minerals to the surface,

[5] Earth ponds are dug out bodies of stagnant water without civil reinforcement and are used for collecting and storage of surface runoff during rainy season.

[6] The study area is inhabited by pastoralists and agro-pastoralists who may have to adapt to eating fish to diversify their food sources.

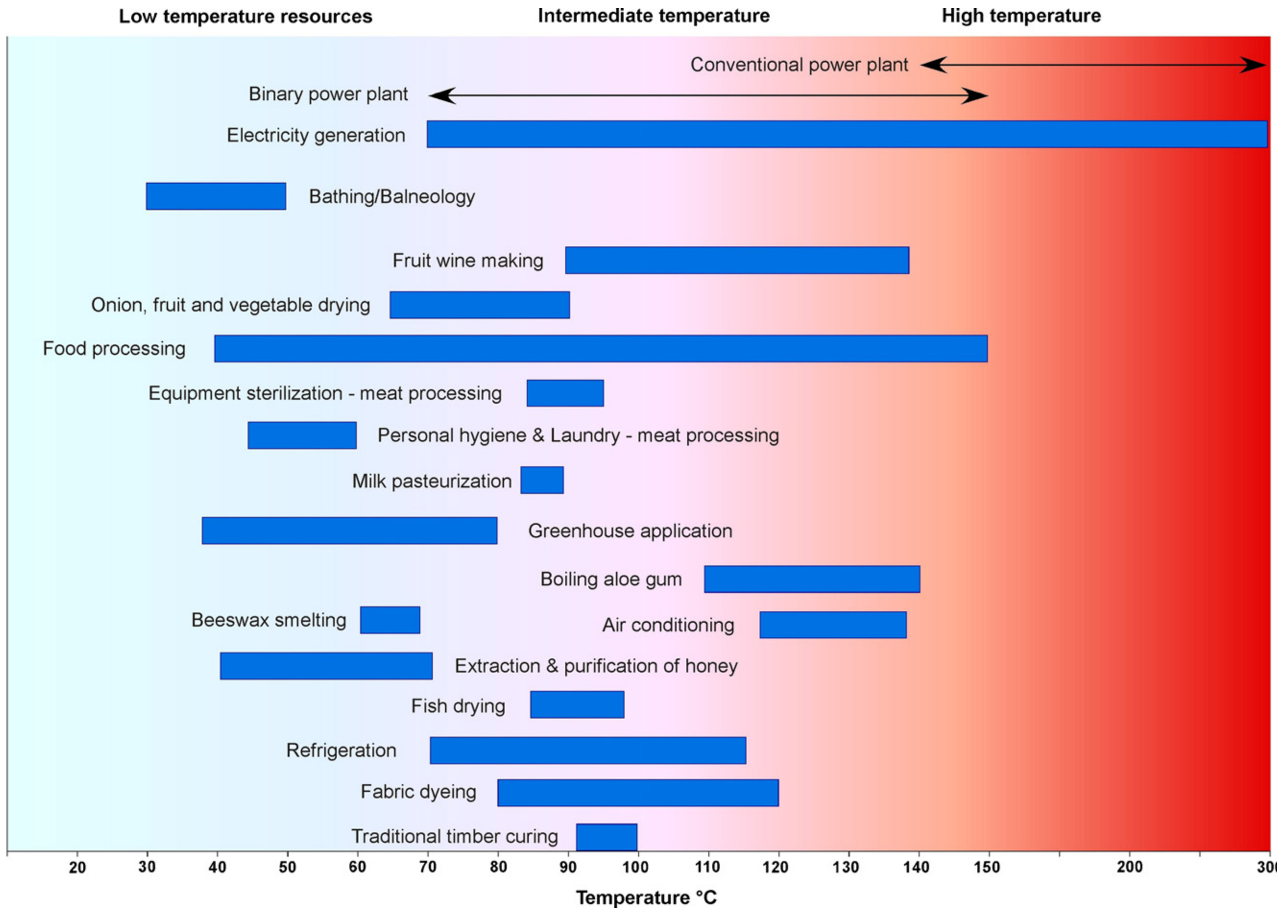

Fig. 22. First Lindal diagram adapted to the study area (can also be adapted to the entire East African rift with more utilisation opportunities).
Source: Authors of this article.

notably sulphur, which collects around the vents as it condenses and solidifies. Thermal waters can be used for extracting ores from rocks (e.g., zinc, manganese, lithium and boron in the US) [102]. Mineral extraction is also done in Japan, at the Dead Sea in Israel and in Russia [103].

Mineral exploration of the study area done in 2009 indicated the presence of the following; ruby, fluorite, red crystal garnets, amethyst quartz and trona. Ten metals were also found in small concentrations e.g., silver (0.7 ppm), gold (0.75 ppm), cobalt (0.96 ppm), chromium (10.4 ppm), copper (1.77 ppm), fluorite (94 ppm), iron (traces), manganese (135 ppm), nickel (85 ppm), zinc (8.8 ppm) and lead (1.02 ppm). Traces of these minerals were also found in laboratory analysis of the stream sediment samples collected. Though the concentrations are low, a study on exploration recommends detailed surface exploration to determine their economic value [104].

Hot springs around Lake Bogoria are rich in CO_2 [24]. Fumaroles at Arus 15 km south of Lake Bogoria, and Esageri, 35 km south of Lake Bogoria discharge CO_2 gas that is up to 99% pure [29]. The non condensable gases can be collected into a CO_2 purifier and compressing plant for production of liquid CO_2 and dry ice. Carbon dioxide mining in Kenya is done by Carbacid Limited and is used in food processing, greenhouse enrichment, pest control, water treatment, fire suppression, and beverage and brewery industries among others.

4.9.2. Link to adaptation

Mining can create employment and other services that can be provided locally hence creating alternative sources of income. However, mining can also lead to removal of vegetation causing soil erosion, pollution of scarce water resources, require large amounts of water for processing, and have a negative impact on tourism if not done unsustainably.

4.10. Others

Potential for geothermal utilisation also exists for local fabric dyeing (e.g., Iwate Prefecture, Japan [105]), pottery production and timber curing, as well as, wool washing (such as in Iceland since the 1960s), and in China for large scale washing and carpet dyeing [106] using temperatures between 60 °C for fine wool and 80 °C for coarse wool.

5. Summary of the potential and adapted Lindal diagram of the study area

This section summarises the utilisation potential in a new Lindal diagram adapted to the study area, gives estimates of the energy required for some processes discussed above (where data on raw material is available), and shows how the processes in the Lindal diagram can be implemented in a cascaded system.

5.1. Adapted Lindal diagram

The potential uses of geothermal energy in the study area discussed above are summarised in the adaptation Lindal diagram (Fig. 22).

The Lindal diagram has been adapted to some of the potential geothermal uses in the study area. The new additions include

Table 1
Estimated thermal energy required for selected processes in the study area. The results are based on estimated of raw material available in the study area and specific energy consumption for similar processes from known utilisation projects.

Process	Available quantity in the study area in tons	Specific thermal energy requirement (kWht/ton)	Estimate units required consumption under present conditions (kWht/year)	Estimated time (h/day)	kWt[a]
Milk processing (Lund and Ref. [69])					
Milk pasteurisation	2000	855	1,710,000	8	572
Full cream powder milk	2000	610	1,220,000		408
UHT	500	190	95,000		32
Evaporated and condensed milk	500	355	177,500		59
Meat processing [109]					–
Beef	300	600	180,000	10	49
Mutton	350	600	210,000		58
Lamb	100	600	60,000		16
Chicken	100	600	60,000		16
Fish head drying [J. Lund]	350	96 000	3,600,000	24	3900
Fruit and vegetable drying [J. Lund]	1000	173,000	173,000,000	24	20,200
Total		274,000	210,400,000		25,300

[a] Lund J. Renewable Energy Laboratory, Golden, CO, USA, pers. comm.; 2010.

geothermal utilisation in honey processing, melting of beeswax, boiling of aloe gum, traditional timber curing and fruit wine making. Existing applications are also included in the diagram. Though this is an initial attempt to draw a Lindal diagram for the study area, the diagram can be expanded and adapted to include more potential geothermal utilisation schemes for the entire Kenyan and African rift where recurrent droughts persist.

Other potential utilisation outside the study area but relevant to the Kenyan Rift include; pyrethrum drying in Eburru, Kenya by local community; tea withering (25–28 °C) and drying (100–120 °C) as in Malabar tea factory, Indonesia [107]; copra drying in Kwale in Coast province (60–70 °C) e.g., Lahendong, Indonesia; [81], grain drying (45–4 °C) [108] as in Kamojang', Indonesia; sisal processing grown in large quantities near Arus geothermal field in Mogotio (south of Marigat); cashew nuts; air conditioning using heat pumps and others. The results of this study can also be upscaled in the entire African rift where applicable.

5.2. Estimated thermal energy requirements for selected activities in the study area

Table 1 shows selected processes where some estimates of raw materials in the study area could be obtained (e.g., milk, meat, fish, and crops) in ton/year. Other processes are not discussed due to lack of data on raw materials. The final thermal energy requirement in kWt is based on availability of products and therefore this table just gives indicative estimates. The specific thermal energy requirement kWht/ton given in the third column was obtained from different authors and experiences used in processing 1 ton of similar products from geothermal energy. The specific thermal energy requirement was multiplied by the quantity of raw materials in the study area to estimate the total energy requirement in kWht/year at 98% availability of the processing plants.

The estimated annual energy required for processes in Table 1 is as follows: milk about 1070 kWt but can vary depending on the type of milk processing preferred by locals; meat about 139 kWt; primary and secondary fish head drying for 140 h (using values from Iceland) and available fish resources in the study area, is about fish 4000 kWt; drying of fruits and vegetable in a single conveyor using examples from US is estimated at 20,000 kWt. The total estimated energy requirement for processing meat, milk, fish and vegetable products is estimated at 210 million kWht/year which is equivalent to 25,000 kWt.

Since the above estimates do not include all the activities discussed in the Lindal diagram, due to lack of data, it may be possible that an estimate of about 100 MWt can adequately meet energy requirements of all activities in the adapted Lindal diagram of the study area using local resources. This estimate is an insignificant proportion of the overall potential.

5.3. Estimated electricity requirement

The current electricity consumption in the area is <1 MWe serving a total of 644 customers (32% domestic and 64% commercial users) with a population of about 250,000 people. Approximately 40% of the available electricity is used by hotels and restaurants which account for 5% of the customers. Retail shops, posho mills[7] and water pumping follow with a total consumption of about 10% each. The rest of the electricity is used for lighting in a few offices and schools in market centres, small irrigation projects and other small scale activities [110].

Due to the small scale nature of activities proposed in this paper, assuming that most activities will consume less than 5 MWe due to the rural nature of the area and based on experiences from energy use in the above sectors, <100 MWe of geothermal energy can adequately cover local adaptation needs for a few years to come. The estimated <100 MWe is based on incremental demand for energy services as the region gradually moves up the energy ladder.

5.4. Utilisation through cascade application

For efficient and economical use of the geothermal resources, cascade application should be considered. Fig. 23 shows how geothermal hot water can be used for different industrial processes in a cascade within different temperature ranges. The temperature ranges shown in the figure define minimum and maximum temperature values required for a geothermal industrial/utilisation process. The number of arrows show the cycle or reuse of hot water from high to low temperatures before the final reinjection.

Electricity from high temperature or binary power plants is also used in the industrial processes as well as water lifting, tourism and other service sectors as shown in the cascade flow diagram. Whereas hot water from binary power plants can be used in downstream cascade activities, high temperature geothermal fluids are sometimes reinjected back into the system without maximum extraction of heat to avoid precipitation of minerals [111].

Electricity production using high temperature geothermal fluids is usually done between 150 and 300 °C. Due to high mineral composition in the high temperature fluids, hot reinjection is done

[7] A posho mill is a mill that grinds wheat or maize into flour.

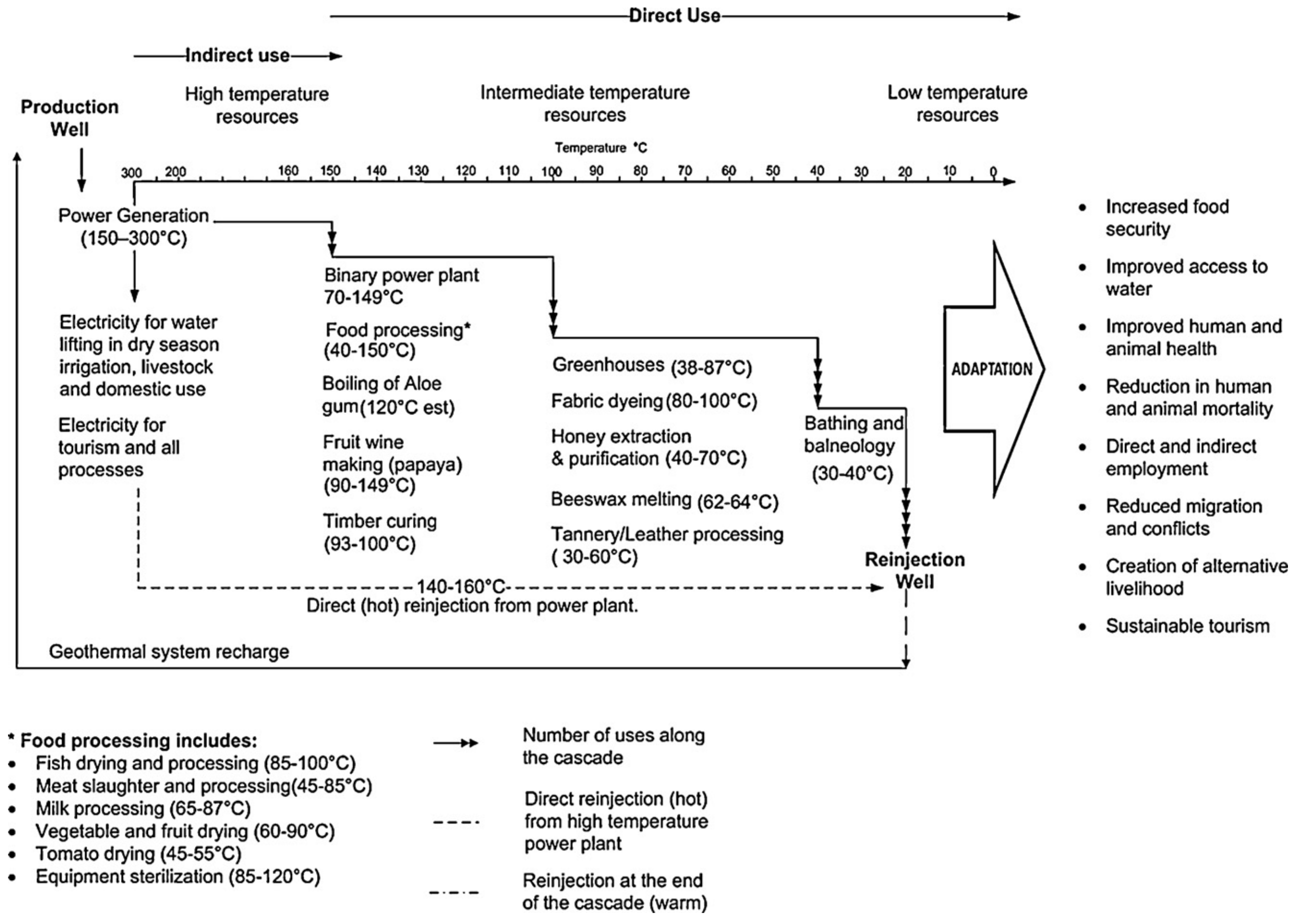

Fig. 23. Potential for cascaded use of geothermal heat in processes relevant to the study area and impact on adaptation.
Source: Authors: original drawing of this article.

at temperatures usually between 140 and160 °C to avoid amorphous silica scaling. Silica concentration in geothermal systems is controlled by quartz solubility and is usually in equilibrium with quartz in the reservoir [112]. The reinjection temperature is retained above the solubility level of the amorphous silica to avoid scaling. Silica (SiO_2) scaling is considered in the design where reservoir temperatures are between 240 and 290 °C and is determined by drop in temperature of separated fluid by 100 °C given by $\sim\Delta t \approx 100$ °C. High reservoir temperatures will require high reinjection temperatures [113]. Alternatively, brine pH modification through acid treatment, polymerisation and use of chemical inhibitors can also be done. Additionally, scaling of calcite ($CaCO_3$) is prevalent in reservoir temperatures between 180 and 240 °C where water begins to boil in the well while silicate and sulphide scaling are common where reservoir temperatures are >290 °C [88].

Most high temperature geothermal resources in the study area discussed in Section 3 of this paper exhibit high reservoir temperatures which can be used for electricity production and reinjected without extraction of additional heat as explained in the flow diagram above. However, in the Lahendong geothermal field in Indonesia, where the temperature in the separated brine is about 180 °C, the brine is directed into a flasher to produce stream of about 4 ton/h used in processing palm sugar for the Masarang farmers [114]. Geothermal steam replaced firewood which was initially used by the local farmers. The Masarang cooperative in collaboration with Pertamina geothermal power company, has improved lives of over 6000 farmers, the quality of sugar palm produced for export and saves about 200,000 trees annually previously cut down by farmers for sugar palm production [115,114].[8] It is possible to consider the Masarang experience from Indonesia in developing high temperature resources within the East African rift to boost local adaptation.

The study area is also endowed with intermediate and low temperature resources which are relatively easy to access and less prone to scaling and can be applied in cascaded direct utilisation projects. The benefits accrued from direct use in industrial processes using local raw materials and services provided by electricity are summarised in the extreme right of the diagram.

6. Discussions

Climate change adaptation needs to be integrated in energy planning at all levels and across all sectors. Development of geothermal resources in adaptation projects, though feasible, can be undermined by technological, financial, investment, legal, communication, environmental and socioeconomic barriers.

The introduction of unfamiliar technologies in the community for adaptation requires the development of technical skills, technology transfer and committed financing, without which the projects will not be possible. Proposed utilisation projects should

[8] The project was submitted for the world challenge global competition in 2007. The competition aims at finding small businesses or projects around the world that show initiative, the innovative use of technology or an invention at community level. The link contains a video sugar palm production using geothermal energy. http://www.theworldchallenge.co.uk/2007-finalists-project07.php.

aim for the best available technology with high energy and water efficiency as well as minimum pollution to reduce the potential of maladaptation. Technologies can be designed for multiple uses and can be disseminated in small scale and managed by organised community cooperatives where possible. Traditional knowledge should be incorporated where necessary.

Furthermore, geothermal development demands high investment costs from exploration, to drilling and production development. Securing financing for geothermal power development might not be as challenging as financing for small scale and direct use industrial activities in the study area [116]. Initial attempts for this kind of utilisation should be tried in a cascaded system from geothermal power plants or bundled into several small projects to attract investments. The government should put in place proper incentives to attract private investment in low temperature utilisation and small geothermal power plants of <5 MWe. This may be achieved either through public–private partnership, public–public partnership, private–community partnerships, non governmental organisations, development partners and other interested stakeholders.

Despite the positive progress in energy reforms and formulation of the new feed in tariff (FiT) in Kenya of US cents 8.5/kWh [117] for geothermal electricity to attract investors, legal barriers related to low temperature utilisation have not been addressed and the tariff has not been fixed. The environmental guidelines and sustainability protocol for such kind of utilisation should also be provided by Energy Regulatory Commission (ERC) and the National Environment Management Authority (NEMA) of Kenya to ensure that the environmental impact assessment (EIA) studies are done within a defined regulatory framework. Integration of geothermal and development in climate vulnerable sectors such as agriculture, water, fishery, etc. should be done through a comprehensive Strategic Environmental Assessment (SEA) to harmonise relevant policy objectives in order to promote integrated development and adaptation. The contribution of geothermal energy and other energy resources should also be clearly stated in the national climate change legislation.

Due to poor infrastructural development in the study area, the initial stages of geothermal development will be slowed by poor accessibility, especially in transportation of equipments and water for drilling and required industrial activities. Water extraction is also required for injectivity testing, cooling systems and a variety of uses in geothermal power production. Since water in the study area is scarce, unsustainable geothermal development and improper disposal of brine can undermine adaptation efforts. Maximum reinjection should be mandatory. Water conservation should be prioritised in all aspects of geothermal development and adaptation highlighted above in order to develop “water smart” geothermal projects. Since the region suffers from alternate years (and seasons) of droughts and floods, flood water can be impounded in dry river valleys using small weirs, stored in water pans and rock catchments. Roof harvesting should also be encouraged. Water intensive activities such as geothermal drilling should also be carried out during or immediately after the rainy season. Such techniques will reduce the pressure from regular sources during the dry season. Exploration for reliable groundwater resources should also be undertaken in the entire region.

In addition to the technical, financial, legal, logistical and environmental challenges, some socioeconomic barriers such as land use and ownership rights, sporadic insecurity and entrenched cultural beliefs may also be experienced during the development of the projects. For instance, geothermal development in the study area is expected to take place within different land ownership tenures (e.g., in the national reserves like Lake Bogoria and Lake Baringo, communal land for grazing, salt licks, and private land). Land adjudication has only taken place in Tugen but not most of the lowlands where geothermal resources occur. This can delay investments and involve lengthy negotiations if the government does not provide clear guidelines especially for land which is communally owned. Effective public consultation, land acquisition, adequate compensation and/or a Memorandum of Understanding (MoU) between the land owners and developers can be reached.

The level of security in the area will also influence the rate of development during the initial stages. Cattle rustling and resource conflicts that are common during droughts are the main sources of insecurity. Though the conflicts tend to be clan or tribal based, and not directed at outsiders, the general safety cannot be ignored due to the use of firearms.

The study area is also endowed with rich undocumented cultural beliefs, some of which are related to geothermal manifestations. There is need for an independent research and documentation of these beliefs and how they can be integrated in geothermal development and promotion of cultural tourism.

Though the above barriers have been discussed in this paper, there is still room for more detailed analysis and discussions in future articles.

7. Conclusion and recommendations

In conclusion, direct and indirect utilisation of geothermal energy is proven in many developed and developing countries, and can be used in adapting to the impacts of climate change in both temperate and tropical climates depending on how it is applied.

Unlike most developing countries where direct use of geothermal energy has been developed for the benefit of the people, no such efforts have been made in Kenya and within the East African rift in general.

This paper therefore presents a new dimension of geothermal utilisation by showing its usefulness in reducing the impact of recurrent droughts within Kenya’s Rift Valley. Though the paper has created an adapted Lindal diagram for the study area with new utilisation schemes, the Lindal diagram can still be expanded to include different utilisation schemes within the entire East African rift in an effort to sow the seeds of geothermal energy utilisation in adaptation.

The use of geothermal energy will improve food security, create employment, reduce drought related losses and provide alternative source of income streams. Direct use of geothermal energy in adaptation is more efficient if used in a cascade of activities through different temperatures shown in the Lindal diagram and cascade scheme in this paper.

The thermal energy required for processing raw materials within a radius of 50 km of the study area is estimated to be 100 MWt and could be less in a cascade system. The required energy can be distributed across the study area using two or more wells with a capacity of 100 kWt–15 MWt depending on the demand and the type of use. Equipment for drilling normal water wells can also be used in drilling low to medium enthalpy resources to fast track local utilisation. The energy can also be sourced from waste heat from the power plants as practiced in the Lahedong geothermal power plant in Indonesia. Some of the processing methods can also be complemented with the use of solar, wind or biogas energy where necessary.

Commercial and domestic electricity consumption in the area is <1 MWe. Due to the small scale nature and rural base of activities described above, the total amount of energy required for utilisation in the study area for adaptation is estimated to be <100 MWe which can easily be sourced from the planned development. The amount of geothermal energy needed in the area for adaptation will not have a significant impact on the water resource. However, development of the entire potential of >2700 MWe could

have some impact on water resources and undermine adaptation efforts if deliberate conservation measures are not taken or reliable groundwater resources discovered. Availability of water for drilling the >2700 MWe will also be a challenge. Geothermal development therefore should be accompanied by extensive catchment preservation in the recharge areas with the help of relevant ministries and institutions as well as maximum reinjection.

Compatibility of different geothermal uses for the proposed projects must be assessed prior to execution in order to avoid conflicting land uses which may also undermine adaptation.

Detailed exploratory studies are still ongoing in the area and additional information to support the existing information is still expected. Geothermal utilisation offers a promising alternative for adaptation within the study area and the entire Kenyan Rift.

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